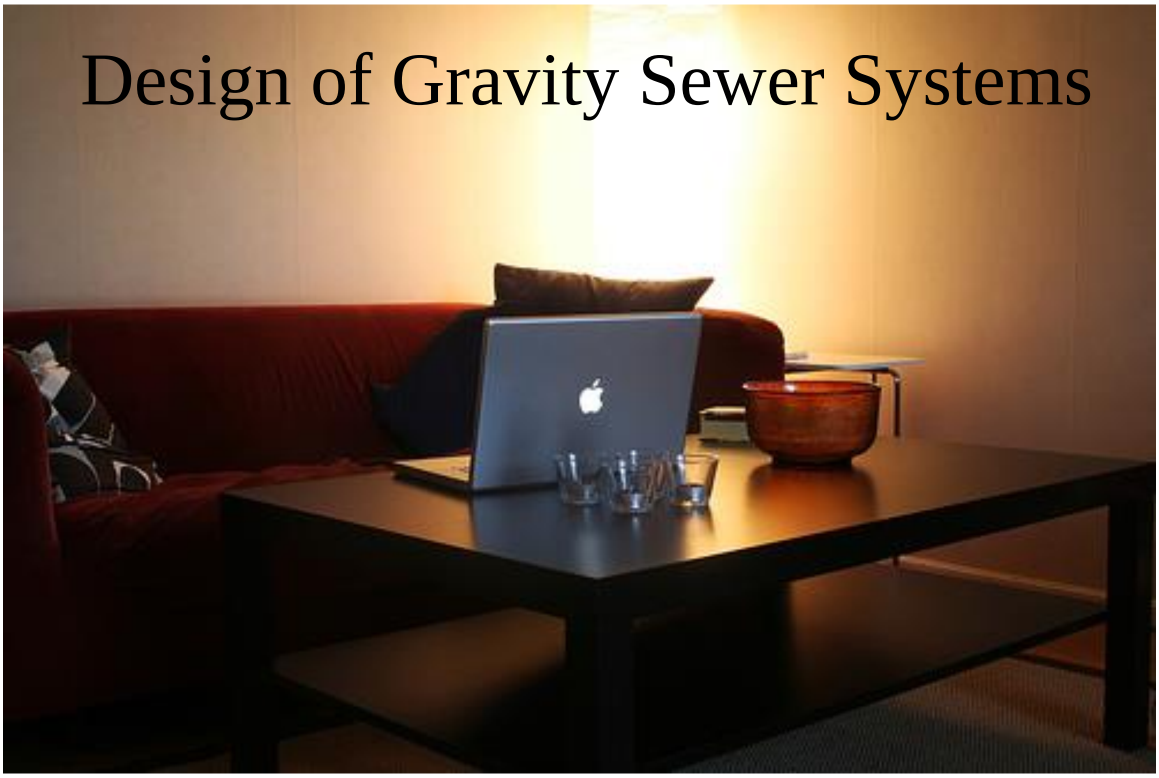

Design of Gravity Sewer Systems

By

Pete Peterson, PE

PDHLibrary Course No 2023012
3 PDH HOURS

DESIGN OF GRAVITY SEWER SYSTEMS

Design Flows

The first step in design of a gravity sanitary sewer system is determination of the design flows. Each service area has its own unique characteristics. For this reason, there is no one correct approach to the projection of flows within a service area. For projects that involve replacement of existing sewers, it is usually possible to install flow measuring devices into the existing system to measure flows at key locations. For projects that involve new sanitary sewers for new developments, it is necessary to estimate the design flows.

The tributary area must be defined. Similar to storm sewer design, the tributary area for a gravity sewer is often all those areas that will drain by gravity through the proposed development. All of these areas should be considered along with adjacent areas that might be developed with a lift station and served by the gravity system.

Once the likely tributary area has been defined it is necessary to establish the proposed land use for the tributary area. If some areas are designated parks or natural areas where zoning prohibits development, these areas should be removed from the calculation. The proposed zoning or land use will determine the population of the proposed area. The values in Table 1 can be used for approximate estimating purposes when no other data is available.

Table 1
Populations vs. Land Use Estimates

Land use	Population
Single Family, Large Lots	5-15 people per acre
Single Family, Small Lots	15-35 people per acre
Multi-Family, Small Lots	35-100 people per acre
Commercial Areas	15-30 people per acre
Industrial Areas	5-15 people per acre

The population estimates can then be used with an average flow per person to develop the overall system flows. In many cases a flow of 100 gallons per capita per day (gpcpd) is used to develop flow estimates. This value has been used for many years and does not necessarily reflect the impact of low flow fixtures on design flows.

In lieu of using the values in Table 1, better data may be available from land use and population data or flow data from the existing system. The assumption that the new development will look similar to adjacent developments is often much better than assuming more general values.

For commercial developments, data from similar developments in the same community or potentially in nearby communities will provide reasonable estimates for flows. For industrial users, discussions with the specific users will be necessary to establish good estimates, but if the sewer line is being extended prior to knowledge of the ultimate user, some conservative assumptions will probably be necessary.

The values noted above are average day flows. In the design of sanitary sewers it is necessary to provide pipes that can convey the peak flows. Peak flows are often calculated based on Figure 1 which comes from a document generally referenced as Ten State Standards, but formally known as “Recommended Standards for Wastewater Facilities” by Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers.

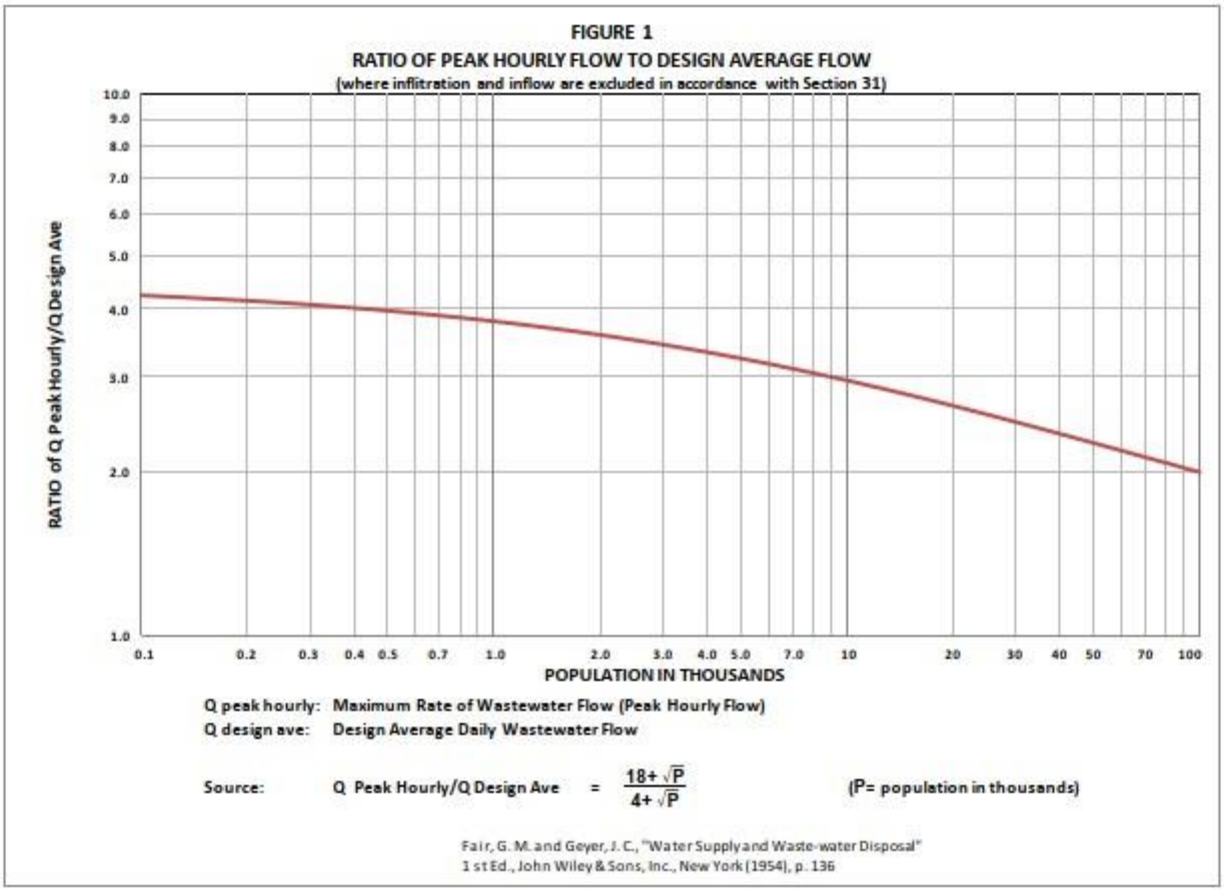

Figure 1 – Ratio of Peak Hourly Flow to Design Average Flow, from Ten State Standards.

The design flow values are then estimate using average per capita flow values times the estimated population times the appropriate peak flow value from Figure 1.

Impacts of Inflow and Infiltration on Design Flows

Design capacity needs to include an allowance for extraneous flows which inevitable become part of the total flow. These flows include groundwater infiltration which enter the system through poor pipe joints and through manholes, which are rarely completely watertight. It also includes inflow from cross-connections to the storm sewer system which are common in older systems and from sump pumps in areas of high groundwater. Finally, there are inflows from surface flows which enter the system either through the manhole cover or through poorly sealed joints between the manhole and the cast iron frame and cover. These flows can be insignificant in some systems and a major issue in others. In some instances, where the design flow is starting to exceed the capacity of the treatment facility, a close look at infiltration and repair or replacement of old pipes can be more cost effective than expansion of the treatment facility. One way to account for some infiltration and inflow is to design the sewer system at 50% or 75% of the full pipe flow capacity. This allows a significant allowance for inflow and infiltration.

Manholes

Manholes are located at all intersections of sanitary sewer lines and at appropriate spacing on straight sections of a sanitary sewer. Depending on the size of the sewer line and the available cleaning equipment, the maximum distance between manholes can vary. Ten State Standards typically recommends a maximum spacing of 400 feet for sewer lines up to 15 inches in diameter and 500 feet for sewers between 18 inches and 30 inches in diameter. When sanitary sewer lines are located on curvilinear streets it is sometimes necessary to reduce the manhole spacing significantly to prevent the sanitary sewer alignment from using the entire street width, which makes installation of other utilities much more difficult.

The primary purpose of a manhole is access to the gravity sanitary sewer. Sanitary sewers convey a wide variety of soluble and solid particles to a treatment facility. Because there are many different solids in a sewer system, a gravity system is susceptible to plugs and clogs. The most common location for these to occur is where multiple lines come together or where the slope of the sewer line changes. With manholes located at these locations, access for cleaning equipment at or close to the clog is provided.

Manholes are typically circular concrete structures with a minimum inside diameter of 48 inches. Manholes are typically constructed in four-foot-long sections, with the bottom section having some variation in depth. The bottom section commonly has a concrete channel constructed connecting the pipes coming in and leaving the structure (see Figure 2). In Figure 2, wastewater enters the manhole from the lower left and the upper left and leaves the manhole in the upper right. The concrete channel constructed in the invert of the manhole provides for a relatively smooth flow transition for this 90-degree change in direction.

Figure 2 – Manhole Invert

The most common upper portion of a manhole is called a cone section (Figure 3). There are two different configurations of cone sections. The section shown in Figure 3 is an eccentric cone section. This cone section has a vertical side (shown on the right in Figure 3) and a steeply sloped side (shown on the left in Figure 3). An eccentric cone section allows for the use of steps on the vertical side of the cone. The other type of cone section is a concentric cone section. This cone section has uniformly sloped sides throughout. Steps are not generally used in a concentric cone since the sides are not vertical. The cone section is typically 4 feet in height and allows a gradual transition from a 48-inch-diameter section to a 24-inch diameter section, which allows the use of a standard manhole cover (see Figure 4).

Figure 3 Eccentric Cone Section

Figure 4 – Typical manhole cover

In some situations, a 4-foot-high cone section is not a viable option. This can be due to limited depth of the manhole. In these conditions, it is possible to use a flat slab top for the manhole. This top will commonly be structurally capable of withstanding highway loads so it can be located near the roadway surface. The opening in the top of the flat slab is typically sized to accommodate the frame for a manhole cover.

Figure 5 – Flat Slab Manhole Top

The top of the cone section, or the top of the flat slab, is usually not set so the frame for the cover will meet the roadway grade. This is due in part to the difficulty in getting manhole sections of the exact height needed for every location. To provide the ability to adjust the elevation of the top of the manhole so it matches the finished roadway surface, adjusting rings are placed between the top of the cone section (or top of the flat slab) and the frame for the cover (see Figure 6). These adjusting rings are usually concrete and vary from 2 inches to 4 inches in thickness. When the manhole is in the street it is desirable the manhole cover match the pavement surface as close as possible. It is possible to purchase adjusting rings that are thicker on one side than the other, which allows for the manhole cover to be installed with a small slope approximately matching the crown (or transverse slope) of the roadway. Where manholes are located outside the paved roadway, the manhole covers should be set above the ground level. This makes locating the manholes easier for maintenance and also reduces the potential that the manhole cover will be slightly below ground and collect surface water.

Figure 6 – Manhole Adjusting Rings

For larger sanitary sewers, manholes must be larger. There are two common methods to connect sanitary sewer pipes to manholes. For smaller pipes, it is most common to use a boot (see Figure 7). A circular hole is cored in the concrete of the manhole after it is poured, or a spacer is used while the concrete is poured. The boot is then placed in this circular opening. The boot has a stainless steel band on the inside that expands as it is tightened and compresses the boot against the concrete of the manhole. The pipe is placed inside the boot and another stainless steel band on the outside of the boot is tightened, compressing the boot against the pipe. This provides a flexible, watertight seal between the pipe and the manhole. The flexibility is important because the manhole often settles slightly differently than the compacted trench so there can be some shear force at the connection. Without a flexible connection, this shear force can break the pipe.

Figure 7 – Manhole Base Section with Rubber Boot

The second method of connecting a pipe to manhole involves cutting a hole in the wall of the manhole. For smaller circular pipes, this can be accomplished by coring the manhole after the concrete is poured. For larger pipes and for arch shapes, this is accomplished in several steps. The first step is to pour the manhole but remove the outside forms before the concrete has cured, and chip out the concrete in the approximate shape of the desired opening (see Figure 8). The concrete is allowed to cure, and the reinforcing steel in the manhole wall provides structural strength for the manhole. This section is then transported to the project site and set in place. Once it has been placed, the reinforcing steel that has been exposed is cut and the concrete in the opening is removed. The new pipe is then placed in this opening and the space between the new pipe and the concrete manhole is filled with non-shrink grout. This provides a watertight joint, but it is not flexible. If there is movement of the manhole, it is possible for the grout seal to be broken, so this type of joint is less desirable.

Figure 8 – Manhole Cutout for Large Diameter Arch Pipe

Regardless of the type of connection used, when the holes are made in the base section for the incoming pipes, the pipes need to be far enough apart to maintain adequate concrete between the openings. If the pipes are too close together, which can happen with large pipes or with acute angles between the pipes (see Figure 9), the pipes may conflict with each other before they enter the manhole. It is generally recommended that at least 12 inches of the manhole wall still be in place after the holes are made in the base (whether by coring or by a block out during construction). This concrete thickness, along with the reinforcing steel, will ensure the structural integrity of the manhole. A typical 48-inch diameter manhole is large enough for smaller diameter pipes (up to 12-inch diameter) entering at 90-degree angles, but when larger diameter pipes are used, or the angle between the pipes is less than 90 degrees, this dimension should be carefully evaluated.

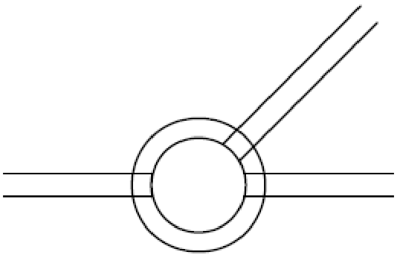

Figure 9 – Manhole Base with Pipes Close Together

Sanitary sewers generally need to be vented. As a general guideline, vents should be provided at a minimum of every 1000 feet of pipeline length. The most common way to vent sanitary sewer lines is with small holes in the manhole cover (see Figure 10). These holes are frequently used by maintenance personnel by placing the pointed end of a pick into the hole and prying the cover off, and thus are sometimes referred to as "pick holes." These holes are about 1inch in diameter and covers usually have 2 holes.

Figure 10 – Manhole Cover with Vent Holes

<u>Sewer Main Location, Depth and Alignment</u>

Sanitary sewer lines are typically located in the street. In some municipalities where alleys are part of the standard design, the sanitary sewer is located in the alley. Sanitary sewer lines can be located in easements along property lines, but this practice is generally discouraged by municipalities, though. Since easements often appear to be part of the adjacent property it is not uncommon for easements to have extensive landscaping installed and maintained by the adjacent landowner. Maintenance of sewer lines in an easement could require large equipment to traverse the easement, or it could require substantial excavation, either of which can create public relations issues with the adjacent property owners.

The specific location in the street cross-section is often dictated by local standards. In some places, sanitary sewer lines are located in the center of the street. This places the manholes in the center of the street where they are not in a driving lane. Another approach is to place the sewer line six fee from the roadway centerline. With a typical 12-foot wide driving lane, this places the manhole in the center of the driving lane, but outside the typical wheel path for vehicles. Manhole covers represent a discontinuity in the roadway surface so it is desirable to keep manholes out of the wheel path. A third approach is to locate the sewer line near the shoulder of the roadway, outside the driving lanes. This is usually the least desirable location since storm water is also generally directed to the shoulder of the roadway. The vent holes in the sanitary sewer manhole then become a direct path for storm water to find its way to the sanitary sewer which is undesirable.

The sanitary sewer lines need to be deep enough to serve all of the adjacent properties. In many locations some of the residences have basements. The floor of a full basement is typically about 6 feet below ground. The footing for the basement wall is often a couple feet below the floor level and the sewer service should be below the footing so the depth of the sewer line at the house should generally be about 9 feet or more. The sewer line from the house is typically a 4-inch diameter pipe (with a minimum slope of 2%) or a 6-inch diameter pipe (with a minimum slope of 1%), depending on local building codes. This service line needs to have a continuous slope from the building to the main and it is desirable for the invert of the service line to be above the top of the mainat the connection point. This often puts the invert of the gravity main at 11 feet or more below ground in the street.

When the street is generally along a contour in a steeper sloped area, the houses on the downhill side of the street could be several feet (or more) below the street grade so the sanitary sewer line needs to be even deeper.

The horizontal and vertical alignment of a gravity sewer line is generally straight between manholes. Vertical changes in alignment will cause a change in velocity in the pipe which can result in deposition of solids so it is desirable for these changes to occur at manholes so it is easy to visually inspect these slope changes for potential deposition. Horizontal changes in alignment also create some flow pattern discontinuities, so these are accomplished at manholes for the same reason. The accumulation of solids can create two potential problems. The most apparent problem is the potential for the solids to partially or completely block the flow. The other problem is the buildup of solids can increase the potential for these solids to decompose within the sewer system which fosters the generation of hydrogen sulfide and methane. These two compounds increase problems associated with smell, increase the corrosion potential and can create hazardous and explosive conditions within the sewer system.

Separation From Other Utilities

Gravity sanitary sewer lines should be located far enough away from other utilities to reduce potential conflicts during construction and during future maintenance operations. Proximity to other utilities makes it more difficult to install sanitary sewer lines. In general, it is desirable that there are no other utilities within the trench of the sanitary sewer, such as gas lines, fiber optic lines, telephone or television line.

Potable water lines are a particular concern. There is the potential for contamination of the potable water when these lines are in close proximity. When both lines are properly installed and there are no leaks, this is a non-issue. However, over time, both sanitary sewer lines and water lines have a tendency to develop leaks in the pipeline. Since the water main is under pressure, the most likely occurrence is for water to leak out of the water main and into the sanitary sewer main. While this increases the flow in the sanitary sewer, there are no particular health issues associated with this scenario. The more concerning scenario is when sewage leaks out of the sewer line and the water main loses pressure, potentially creating a small vacuum. This can allow contaminated water to infiltrate into the water main, creating a significant health concern.

Typical design requirements for separation of sanitary sewer and water mains include a 10-foot horizontal separation (from the outside of the water main pipe to the outside of the sanitary sewer pipe) and an 18-inch vertical separation when these lines cross. Most standards allow for a reduction in the 18-inch vertical separation by using water main class pipe for the sanitary sewer for a distance of at least 10 feet on each side of the crossing. This creates several problems these regulations don't address, however. When a short (approximately 20 foot long) section of water class pipe is placed in a gravity sewer line, both the inside diameter and the outside diameter of the water pipe are typically larger than the diameters of the sewer pipe. This results in a flexible connector being used at both ends of the short section of water pipe. This flexible connection will have much less integrity than the standard push on joint, so there are now two lower-quality joints near the water main. With the inside diameter of the water main larger than the inside diameter of the sewer main, and the flexible connector providing a connection that matches the pipe centerlines, at the downstream end of the water pipe there is a lip in the flow line which can cause materials to hang up, eventually creating a partial or complete blockage. While this configuration is allowed by the regulations, it is not a recommended configuration due to these problems.

Storm sewer lines can create a special problem, since both the sanitary sewer line and the storm sewer line are likely to be gravity lines and conflicts are much more difficult to resolve.

Pipe Size and Slope

Before the pipe size can be determined it is necessary to determine the available pipe slope. The ideal situation is the pipe slope matches the slope of the street above the pipe and still meets the minimum slopes. It is therefore necessary to establish the roadway grades prior to final design of the sanitary sewer slopes.

In some situations, the existence of other pipelines, primarily oil and natural gas transmission lines, will influence the available slope of a sanitary sewer line. These pipelines are typically difficult and expensive to move so it is usually necessary to design the sanitary sewer line around these other transmission lines.

Once the general slope of the streets in the area has been determined, the first attempt at pipe sizing can begin. Determining appropriate pipe size and slope is often an iterative procedure. It is generally most effective to start at the highest lot in the development and work downhill. Table 2 presents the minimum slope for each pipe size. These values come from Ten State Standards and are sometimes slightly modified for a municipality. The slopes are based on achieving a minimum velocity of 2 feet per second at full pipe flow with a Manning's n value of 0.013. This is also the velocity when the pipe is flowing half full. Sewers 48-inch diameter and larger should generally be designed to give mean velocities of 3 feet per second when flowing full.

Table 2
Minimum Slope
Gravity Sanitary Sewer Pipe

Nominal Sewer Size	Minimum Slope, %
8	0.40
10	0.28
12	0.22
15	0.15
18	0.12
21	0.10
24	0.08
27	0.067
30	0.058
33	0.052
36	0.046
39	0.041
42	0.037

The flow capacity of a gravity pipe is typically computed using Manning's equation:

$Q = (1.49/n)\,AR^{2/3}$

Where Q = flow in cubic feet per second (cfs)

n = Manning's roughness coefficient

A = Inside area of the pipe, $\pi D^2/4$

P = Wetted perimeter of the pipe, πD

R = Hydraulic Radius, A/P = D/4

In most jurisdictions, the minimum pipe size for a gravity sanitary sewer system is an 8-inch diameter pipe. There are a variety of approaches to the maximum allowable flow depth in a sanitary sewer. In some jurisdictions, it is allowable for the pipe to flow full at peak hour. In other jurisdictions, the maximum allowable flow is 50% or 75% of the full pipe flow. For discussion purposes in this course, it is assumed the allowable capacity of a pipe is the full pipe flow.

An 8-inch diameter pipe at minimum slope (0.40%) has a full flow capacity of about 271 gpm. For a new development with an average of 3 people per household and 100 gpcpd, a single home would have an average demand of about 300 gpd. With a peak flow factor of 4.5 from Figure 1, this would be about 1350 gpd, or about 0.94 gpm. An 8-inch diameter pipe would be able to serve about 271/0.94 = 288 homes. This calculation, adjusted to account for appropriate populations, average flow rates and peak factors can be very useful in system design. Large portions of the system can be designed using 8-inch diameter pipe without further hydraulic calculations.

Flows in a sewer system will typically follow a diurnal curve very similar to the water use. Figure 11 shows an example of a diurnal curve for a system. Flows tend to be very low at night, increase in the morning as people prepare to go to work and school, level off through much of the day, then increase in the evening as people return home to take care of food preparation, washing dishes and washing clothes. During periods of low flows, the flow and associated velocity in the sanitary sewer will much lower than the peak values.

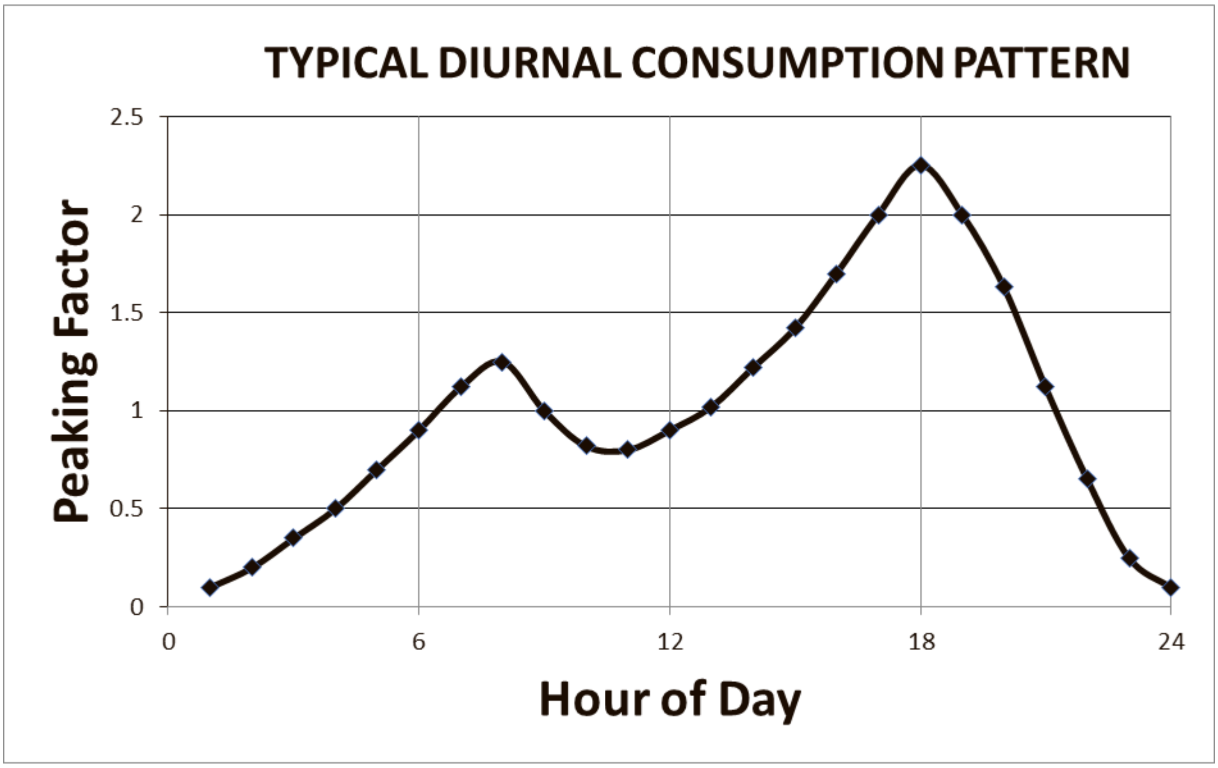

Figure 11 – Typical diurnal curve

While the values in Table 2 are minimum slopes, it is not good engineering practice to use these slopes unless absolutely necessary. While velocities of 2 feet per second are generally adequate to keep solids from depositing in the pipe, these velocities are only achieved when the pipe is flowing at least half full. To achieve half full flow in an 8-inch diameter pipe, based on the calculation above, even during peak hour conditions would require about 144 homes. The use of greater slopes to increase the velocity during periods of low flow will reduce the number of blockages in the system and consequently reduce the maintenance costs.

In some instances, where minimum slopes are not easily achieved, design engineers will use larger pipes and install them at minimum slopes, even when the additional flow capacity of a larger pipe is not required. This practice is not recommended and many jurisdictions no longer allow this approach. This practice is specifically prohibited by Ten State Standards, for jurisdictions that incorporate these requirements.

To promote good flow through the manhole, the invert elevation of the pipe going out of the manhole is set lower than the invert elevation(s) of the pipe(s) coming into the manhole. The amount of change in elevation varies depending on local standards. In many jurisdictions, the difference is 0.1 foot. However, some jurisdictions prefer more drop across the manhole and 0.2 foot is used. This elevation difference ensures there is adequate slope through the manhole to maintain flow and to account for potential energy losses where there are two or more influent pipes and flows come in from different directions. It also accounts for energy losses due to changes in flow direction through the manhole.

In some instances, the incoming pipe is at a much higher elevation than the outgoing line. This is more common when there are multiple incoming pipes and one of them serves only a small area so it is not as deep. It is generally undesirable to have a pipe invert come into the manhole at an elevation significantly higher than the invert of the manhole. Therefore, a drop manhole is commonly used and required. Some jurisdictions prefer to use an inside drop manhole (see Figure 12), which the drop structure located inside the manhole. The use of an inside drop manhole usually requires the manhole to be larger than a standard 4-foot diameter manhole. Other jurisdictions prefer to use an outside drop manhole (see Figure 13) where the drop structure is located outside the manhole and is typically encased in concrete. Most jurisdictions require a drop manhole when the elevation difference between the pipe invert and the manhole invert is 2 feet or more. Figure 14 shows an example profile that incorporates drop manholes. This profile allows for relatively shallow construction depths which reduces the amount of excavation.

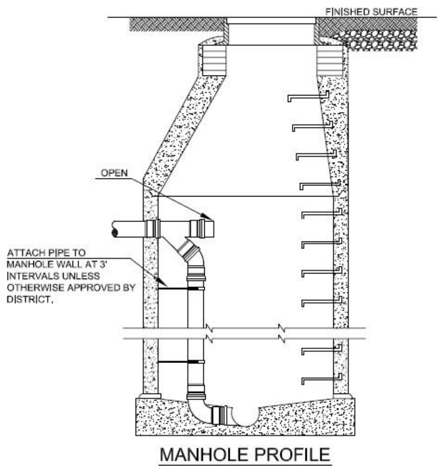

Figure 12 – Inside Drop Manhole

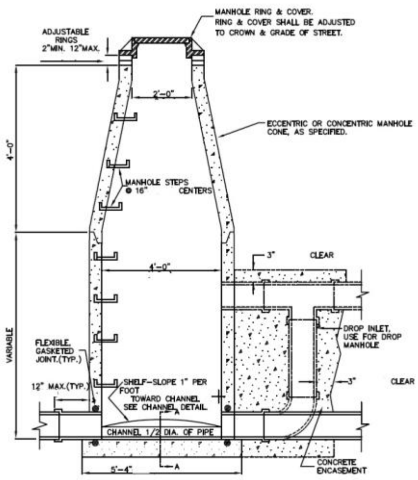

Figure 13 – Outside Drop Manhole

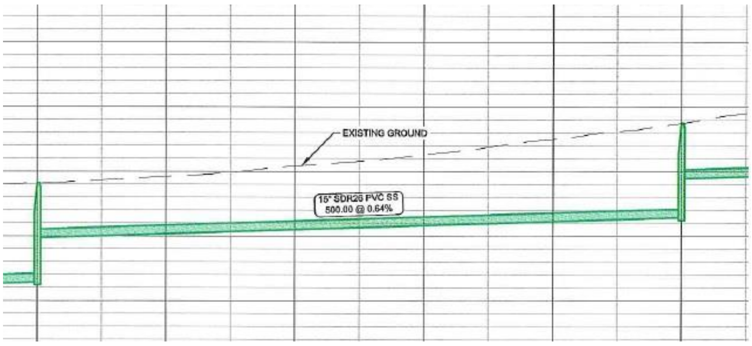

Figure 14 – Sewer Profile using Drop Manholes

Pipe Materials

In sanitary sewer mains, the fluid being transported carries significant organics, which will decompose with time. This decomposition releases gases into the piping system. These gases can combine with condensation on the top of the pipe to create strong acids, which can be detrimental to the pipe material. Reinforced concrete pipe has historically been used for large sanitary sewers, but many municipalities have had pipe failures due to the crown of the pipe deteriorating because of these acids. Some pipe materials that are suitable for storm sewer use are not suitable for sanitary sewers due to the corrosion issues.

The most common material used to transport sanitary sewer is PVC, in part due to its corrosion resistance. In most cases, the pipe material has a stamp on the outside of the pipe that identifies the specific design parameters for each piece of pipe, such as SDR rating for PVC pipe. This aids the design engineer, owner and resident project representative in determining that the material on site meets the required specification.

Gravity pipes are usually installed in a straight line between junctions, and concrete manholes are placed at these junctions. As a result, there are very few fittings associated with gravity pipes, with the exception of fittings used for service connections.

Solid Wall PVC

Solid Wall PVC pipe for gravity purposes is generally available in two thicknesses. The most common thickness used is SDR 35 (see Figure 15). The SDR is the Standard Dimension Ratio and is the ratio of the outside diameter to the wall thickness. In the case of 8-inch diameter PVC, the outside diameter is 8.40 inches and the wall thickness is 0.24 inches, so the SDR is 8.4/0.24 = 35. The other common thickness is SDR 26. For 8-inch diameter SDR 26 pipe, the outside diameter is the same as SDR 35, but the wall thickness is 0.323 inches (about 35% thicker than SDR 35).

The strength of flexible gravity pipes is often described using Pipe Stiffness (PS). The pipe stiffness is the force required to deflect the pipe 5% of its inside diameter. SDR 35 pipe has a pipe stiffness of 46 psi and SDR 26 pipe has a pipe stiffness of

115 psi. In some jurisdictions, the standard requirements for gravity PVC require the use of SDR 26 pipe rather than SDR 35 pipe. This is often due to concerns about the structural strength of SDR 35 pipe. Although SDR 35 pipe is suitable for relatively deep depths, good quality construction is necessary to provide a suitable envelope around the pipe to support this flexible material.

Some PVC pipes for gravity service are very thin. For example, PVC pipe meeting ASTM D2729 is available in SDR 56. This pipe is sometimes used for individual sewer systems and service lines but is very susceptible to cracking due to the low strength. Schedule 40 and Schedule 80 pipe meeting the requirements of ASTM D1784 are also sometimes used for gravity applications. The joints for PVC gravity sewer pipe are typically gasketed joints. These joints are similar to the joints for PVC pressure pipe but are not designed to withstand significant pressures. They can withstand limited pressure (a few psi) and properly constructed can easily pass the air test that is typically required for sewer pipes. The interior walls of PVC pipe are very smooth, so a low Manning's n roughness values is appropriate. Laboratory testing indicates the n value could be as low as 0.010 for clean water. However, in gravity applications, the fluid being transported is not clean water and some settling of solids can occur. An n value of 0.012 or 0.013 is commonly used for design purposes.

Figure 15 – Solid Wall PVC Gravity Pipe

Profile Wall PVC

Another PVC pipe product that can be used in gravity flow applications is profile wall PVC (see Figure 16). There are a number of different manufacturers of this product, and each product looks a little different. The pipes meet ASTM F794 "Standard Specification for Poly (Vinyl chloride) (PVC) Profile Gravity Sanitary Pipe and Fittings Based on Controlled Inside Diameter". This pipe has two walls. The interior wall is smooth which provides the low friction factors that are desirable. The exterior wall is ribbed or corrugated and provides structural strength in the same manner as in corrugated metal pipe. The two walls are fused together during the manufacturing process. Due to the structural strength provided by the exterior wall, the overall weight of the product is much lower than for similar solid wall PVC pipe. For example, 18-inch diameter profile wall pipe weighs about 10 pounds per foot, whereas 18-inch diameter solid wall PVC pipe weighs about 21 pounds per foot.

This pipe is available in sizes from 4-inch diameter to 36-inch diameter but is generally used in larger diameters. The smooth interior of profile wall PVC provides a friction factor that is the same as solid wall PVC. The pipe has a pipe stiffness of 46 psi, which matches the pipe stiffness of SDR 35 pipe. It is not readily available in higher pipe stiffness to match SDR 26 pipe. The joints for profile wall pipe are typically a bell and spigot gasketed joint, with the gasket specially designed to fit over the corrugated exterior of the pipe.

Figure 16 – Profile Wall PVC Pipe

Ductile Iron/Cast Iron Pipe

Cast iron pipe has been widely available since the turn of the 20th century. Cast iron pipe used for sanitary sewer applications is often referenced as cast iron soil pipe. Cast iron soil pipe is generally available in sizes from 3-inch diameter to 15-inch diameter. Ductile iron pipe is also used for sanitary sewer applications. Ductile iron gravity pipe is generally available in the same sizes as pressure pipe – 3-inch diameter to 64-inch diameter.

Ductile iron pipe is typically furnished with a cement mortar lining. However, the gases that are formed during decomposition of the organic matter in sanitary sewers can combine with condensation in the pipe to create acids that attack the lining. Therefore, common cement-mortar lined ductile iron pipe should not generally be used for gravity sanitary sewer applications. It is usually suitable for force main applications, because a force main is typically always full of fluid, so the gases are not released in the same manner as in a gravity sewer line.

Ductile iron pipe can be furnished with no lining, but the acids can also react with the iron and deteriorate the pipe. Special linings are available to protect the interior of ductile iron pipe from these acids. An example of a special lining for ductile iron pipe is shown in Figure 17.

Ductile iron pipe for sanitary applications has the same joint options that are available for pressure pipe – push on, mechanical and flanged. Push on joints are almost always used for gravity applications because there are no thrust forces to resist. The cement mortar lining creates a surface very similar to concrete pipe, so a friction value similar to that for concrete pipe would be appropriate, such as a Manning's n value of 0.013. Unlined cast iron would have a potentially much higher friction factor, especially after it has been in service for a number of years.

Figure 17 – Epoxy coated ductile iron pipe

Reinforced Concrete Pipe

Reinforced concrete pipe (RCP) is commonly used in storm sewer applications but is not recommended for sanitary sewer applications due to the corrosive nature of sanitary sewers.

Corrugated Metal Pipe

Corrugated metal pipe includes both steel pipe and aluminum pipe. In general, these products are most often used for culvert applications and are not used for sanitary sewers due to corrosion concerns. In addition, the nature of the corrugations would promote solids deposition which would be very undesirable.

Corrugated High Density Polyethylene (HDPE)

Corrugated HDPE is made of high-density polyethylene. The corrugations provide significant strength to resist live and dead loads in a gravity application. The pipe stiffness for HDPE pipe varies by diameter. HDPE pipe with a diameter of 12-inches has a pipe stiffness of 50 psi while 60-inch diameter pipe has a pipe stiffness of only 14 psi. This means that larger diameter HDPE pipe is much more flexible than PVC pipe and requires better bedding and better installation practices. Corrugated HDPE is available as single wall pipe and double wall pipe. The single wall pipe is just an exterior corrugated wall and the interior is also corrugated, and consequently this material has a very high friction factor and is not suitable for sanitary sewer applications. Double wall pipe has a corrugated exterior wall and a smooth interior wall, with produces a much lower friction factor and also provides a stronger pipe. Corrugated HDPE is lighter than PVC – 18-inch diameter double-wall HDPE only weighs about 6 pounds per foot, compared to 21 pounds per foot for solid wall PVC.

Corrugated HDPE pipe is made with annular corrugations, similar to some corrugated steel pipe. For double wall HDPE, the friction factors are similar to profile wall PVC or solid wall PVC. The joints for HDPE pipe are typically bell and spigot (see Figure 18). This joint includes a gasket which can make the joint watertight. However, the flexibility of this pipe, as indicated by the low pipe stiffness, can make it somewhat difficult to construct a watertight system. More care is required by the contractor to accomplish this task, and air testing is strongly recommended to ensure the completed installation is watertight.

Figure 18 – HDPE Pipe, Bell End (left) and Spigot End (right)

Vitrified Clay

Clay pipe has been in use in the United States for over 150 years and has been used in some places for over 2500 years. Clay pipe is generally available in sizes from 4 inches to 42 inches. Based on information from the manufacturer's association, there are over one million miles of clay pipe installed in the United States. It was a very common material for many years and numerous manufacturing facilities were scattered across the U.S. There are only a few manufacturing facilities remaining in the United States, though. In areas that are in reasonable proximity to a manufacturing facility, clay pipe is very viable option. In areas that are not near to a manufacturing facility, the transportation costs for clay pipe tend to make it non-competitive from a cost standpoint, although it is an acceptable option.

Clay pipe is manufactured by firing the material at 2000° F. At this temperature, vitrification occurs as the clay mineral particles become fused into a chemically inert and stable material. The wall thickness can vary depending on the type of clay raw materials and the processes used in the plant to achieve strength requirements. The inside diameter of the pipe is controlled, but the outside diameter varies depending on the raw materials used.

Clay pipe is now provided with a gasketed joint (see Figure 19). For centuries, clay pipe was provided simply with a coupling or push-together joint. Sometimes a sealant was provided in this joint, and sometimes it wasn't. Many old clay pipes have a very simple connection that allows water in and out of the pipe. This promotes invasion of roots that can clog the pipe, so many engineers don't use clay pipe based on problems associated with older versions of the joint. The current joint configuration provides a water-tight joint that can meet the air testing requirements for sanitary sewers. Clay pipe is a rigid pipe, so pipe stiffness is not a design consideration. Pipe strength to resist live loads and dead loads is a design consideration, though.

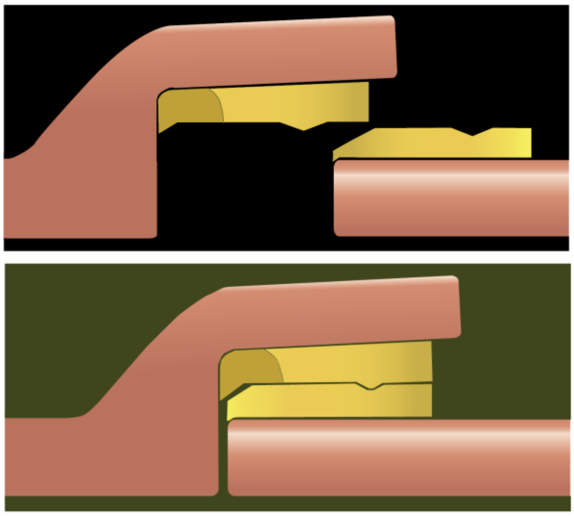

Figure 19 – Clay pipe gasketed joint

Profile Wall Polypropylene

Profile wall polypropylene is similar to profile wall PVC and to corrugated HDPE. It is usually a double wall pipe, with a corrugated exterior wall and a smooth interior wall. It is available in sizes from 12-inch diameter to 60-inch diameter.

Double wall pipe (see Figure 20) with a pipe stiffness ranging between 46 psi (matching SDR 35 PVC) and 75 psi is available for sanitary sewer applications in sizes from 12-inch diameter to 30-inch diameter. Triple wall pipe (with a third wall, which is a smooth exterior wall) for sanitary sewer applications is available in sizes from 30-inch diameter to 60-inch diameter with a pipe stiffness of 46 psi (again to match SDR 35 PVC). As noted with larger diameter HDPE, with a pipe stiffness less than 46 psi, even more care during installation is required.

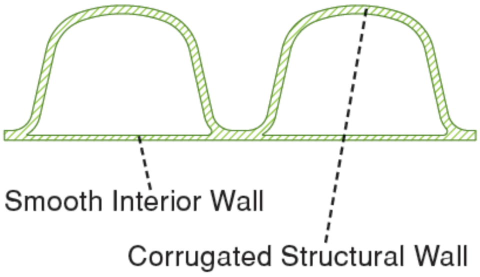

Figure 20 – Cross-section of Profile Wall Polypropylene

The joint for profile wall polypropylene pipe is typically a bell and spigot, gasketed joint (see Figure 21). This joint is similar to that for corrugated HDPE and incorporates a gasket that can provide a water-tight joint and meet air testing requirements for sanitary sewer. The interior wall is smooth and therefore a friction factor similar to solid wall PVC or profile wall PVC is appropriate.

Figure 21 – Bell and Spigot Joint for Profile Wall Polypropylene

Steel Reinforced Corrugated HDPE

Steel reinforced corrugated HDPE is very similar to corrugated HDPE, except that steel reinforcing ribs are included in the corrugations, providing a stronger cross-section (see Figure 22). The available pipe sizes depend on the manufacturer but vary from 12-inch diameter to 120-inch diameter.

This pipe combines the strength of steel with the corrosion resistance of HDPE. The joints are typically a bell and spigot joint with a gasket, although some other joint types are available. The gasketed joint can provide a pipe system that can meet the air testing requirements for sanitary sewer (see Figure 23). The smooth interior allows the use of a Manning's n value the same as corrugated HDPE or solid wall PVC.

Figure 22 – Steel Reinforced Corrugated HDPE Cross-Section

Figure 23 – Installed Steel Reinforced Corrugated HDPE

Centrigually Cast Fiberglass Reinforced Polymer Mortar
Centrigually Cast Fiberglass Reinforced Polymer Mortar (CCFRPM) pipes are specialty pipes made by a single manufacturer in the United States. The pipes are sometimes refered to as Hobas pipes, after the manufacturer.

The pipes consist a a number of different layers of material. Starting from the outside of the pipe, they consist of:
Outer layer – sand and resin
Heavily reinforced layer – chopped glass and resin
Transition – glass, resin and mortar
Core – Polymer mortar
Transition – glass, resin and mortar
Heavily reinforced layer – chopped glass and resin
Liner – high elongation resin

The two heavily reinforced layers (see Figure 24) function similarly to the flanges of an I-beam, with the core functioning as the web of the I-beam. This design provides significant strength. The pipe is manufacturered using a continuous casting process. The pipe is available in sizes from 18-inch diameter to 126-inch diameter. While this pipe includes mortar and reinforcement, it is considered a flexible pipe not a rigid pipe. Depending on size, it is available in pipe stiffnesses of 18 psi, 36 psi, 46 psi and 72 psi.

The joints for these pipes can have a variety of different connectors. Bell and spigot joints area available along with several different couplings. All of the joints are water-tight and can meet the air-testing requirements of sanitary sewers. These large diameter pipes are ideally suited for nearly all corrosive piping applications. Pipes can be individually designed for non-pressure and pressure service by varying the quantity, placement, and orientation of the glass-fiber reinforcements. While this is a proprietary product and a specialty product, it is very resistant to the corrosion of sanitary sewers and can be a viable product in that application. The interior lining is very smooth so the friction factor is at least as low as any of the other products described.

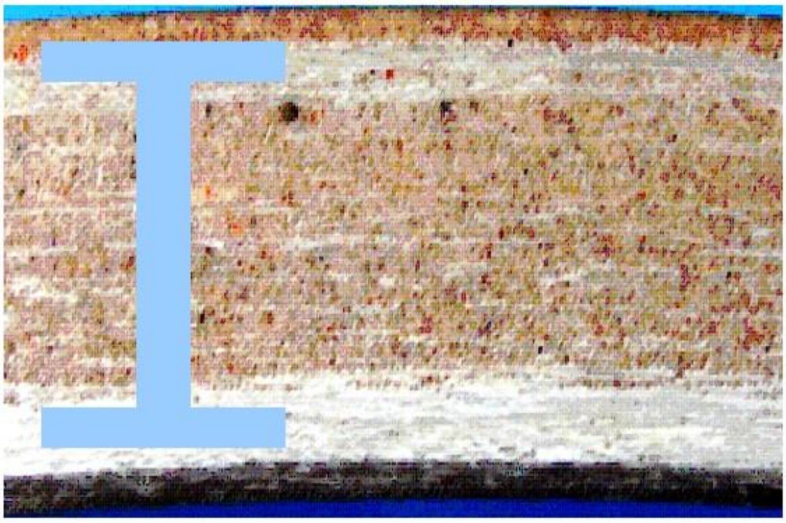
Figure 24 – CCFRPM cross-section

Bedding and Backfill

Proper installation of any pipe material requires appropriate bedding and backfill. Bedding commonly refers to the material under and around the pipe and backfill is the material above the pipe, to the ground surface. Most of the pipes used for sanitary sewer applications are flexible pipes. These include ductile iron (although it is obviously not as flexible as other materials), PVC, HDPE, polypropylene and CCFRPM. The only rigid pipes used for pressure and sewer applications are reinforced concrete and clay.

When rigid pipe is installed, most of the structural components of the installation arrive on the truck in the form of the pipe. When flexible pipe is installed, the pipe essentially functions as a form for the structure, similar to the forms used in concrete construction. The structure for flexible pipe is created by the contractor by installing bedding and backfill under, around and over the pipe. It is therefore very important that the bedding and backfill be appropriate materials and be installed correctly. A flexible pipe deforms slightly (becoming egg-shaped) and this deformation transfers the vertical load (live load and dead load) from the top of the pipe to the soils on the sides of the pipe. If the soils around the pipe do not provide solid support, the pipe will deform excessively, causing premature failure of the pipe.

There are several zones of material that are important in the installation of pipe.

Starting at the bottom of the trench, the first zone is the bedding material under the pipe. This material is often a granular material, sometimes washed gravel because it is easy to work with and provides good support. This material is required to bring the trench bottom up to the desired grade, which is critical in installation of gravity pipe. This material also provides uniform longitudinal support under the pipe. For pipes that have bell and spigot joints (all of the pipe materials discussed have this type of joint), a small amount of bedding will be removed from under the bell, to allow the pipe to be installed on grade. Under normal conditions, a depth of bedding of 4 to 6 inches under the pipe will be suitable. If the native soils at the level of the pipe bedding are fine-grained soils, there is the potential for these soils to migrate into the bedding material over time. If this happens, eventually the surface of the trench will settle which is usually an undesirable condition. To prevent this, the use of well-graded bedding material which reduces the void spaces available for migration or a fabric to separate the bedding material from the native soils.

The next zone of material is the pipe zone, which is material adjacent to the pipe. This zone includes the haunch of the pipe which is the area below the centerline of the pipe (sometimes called the spring line of the pipe). It is important to get material against the lower part of the pipe, but this takes some care during construction to ensure that an adequate amount of material is placed under the haunches of the pipe, but not so much material that the grade of the pipe is changed. A flowable material such as washed gravel or sand is often used to make this easier. A high degree of compaction is not usually necessary for this layer of material, but this material does need to be compacted uniformly.

The material from the centerline of the pipe to the top of the pipe needs to be carefully placed to continue to create the structure for the installation and a high-quality material is needed. Sometimes the native soils are suitable for use above the spring line of the pipe. Installation should be in lifts, installed uniformly on both sides of the pipe to maintain the circular shape of the pipe. If too much material is placed on one side before any material is placed on the other side, the pipe will lose its shape and its ability to resist additional loads.

The first layer above the top of the pipe is also part of the pipe embedment zone. This material should be select material, with no rocks greater than 1.5 inches in size, no lumps of dirt, frozen material or organic material. This material provides protection for the pipe from objects that may fall into the trench and needs to be well-compacted to provide the necessary structural support.

At shallow depths of cover (less than 3 feet) flexible conduits may deflect and rebound under traffic loading if the trench is not well compacted. This can result in damage to the roadway surface because pavements are not designed for this amount of repeated deflection. In this situation, all of the backfill material should be granular material.

Depth of Cover

Pipe manufacturers generally provide minimum and maximum depths of cover for their products. However, the manufacturers are not all consistent on the parameters used to make recommendations for allowable depths of cover. The loads on a pipe include live loads and dead loads. The live loads depend on the use of the surface and the depth of the pipe. A summary of these loads is shown in Table 3 for highway, railroad and airport conditions. Note that the surface use impacts the live loads significantly and the live loads decrease quickly with additional depth.

Table 3
Live Loads
Based on Surface Use and Cover

Height of Cover (ft)	Live Load Transferred to Pipe, psi		
	Highway	Railway	Airport
1	12.5	*	*
2	5.56	26.39	13.14
3	4.17	23.61	12.28
4	2.78	18.49	11.27
5	1.74	16.67	10.09
6	1.39	15.63	8.79
7	1.22	12.15	7.85
8	0.69	11.11	6.93
10	*	7.64	6.09
12	*	5.56	4.76

The recommended minimum cover for different pipe materials is shown in Table 4. Note that the cover for HDPE, which is a very flexible material, is less than that for ductile iron or steel. Keep in mind that these are manufacturers recommendations and while protection of the pipe is important, protection of the surface, especially if it is pavement, is also important.

Table 4
Minimum Cover for Pipes
Based on Manufacturers Recommendations

Pipe Material	Minimum cover, ft
Ductile Iron	2.5
SDR 26 and SDR 35 PVC	3 *
Corrugated HDPE	1
Concrete	1 – 2 **

* Can be reduced to one foot with a backfill envelope of granular materials
** Depending on diameter

The recommended maximum cover for different pipe materials is shown in Table 5. Again, these are manufacturers recommendations. For maximum cover, the class of the pipe in ductile iron, PVC, steel, HDPE and concrete makes a difference. In many cases, the type of soil material in the bedding and backfill also influences the maximum cover. The values shown in Table 5 should be verified for every installation.

Table 5
Maximum Cover for Pipes
Based on Manufacturers Recommendations

Pipe Material	Maximum cover, ft
Ductile Iron	20 - 50
SDR 35 PVC	20
Corrugated HDPE	20
Concrete	15 - 50
Clay	20

Leakage Testing

Leakage testing of gravity pipes after installation is highly recommended. It is usually required for sanitary sewers and is recommended in all cases. The leakage test ensures that the sewer line has been properly installed. It is also common for most projects to require a video camera be used through the pipeline to look for obvious problems (such as rolled gaskets or joints that have pulled apart). Some jurisdictions prefer to only do the video examination, thinking that it is possible to see all of the problems and that the leakage test is an unnecessary expense. However, it is very possible for a small crack in a pipe or a bad joint to be essentially undetectable by camera, but the imperfection would allow enough air to leave the pipe that a leakage test would fail. A crack or bad joint in a newly constructed pipe certainly should not be allowed, so it is recommended that testing for gravity lines include a leakage test.

There are two types of leakage tests performed on gravity pipes. The preferred method is usually an air test. A leakage test using water can be performed, but this is a more cumbersome test and requires significant quantities of water. The air test is performed by plugging both ends of a section of pipeline at the manhole and then pressurizing the air within the pipeline. The air pressure is usually raised to 4.0 psi, lowered to 3.5 psi through a valve, then the time is measured for the pressure to drop to 2.5 psi. The minimum allowable time for this pressure drop is calculated based on 3.5 cubic feet per minute or 0.003 cubic feet per minute per square foot of internal surface area of the pipe being tested. If the pressure drop takes longer than the allowable time, the test is successful.

Deflection Testing

Ten State Standards require deflection testing for flexible pipes, to ensure that pipe deflection (at least 30 days after installation) does not exceed 5% of the pipe diameter.

Design of Gravity Sewer Systems - Quiz

Updated: 6/24/2023

1. In the design of sanitary sewer systems, which of the following flows are used to size pipes?
    a. Average day flows
    b. Peak day flows
    c. Minimum flows
    d. None of the above

2. What is the more common name given to the Recommended Standards for Wastewater Facilities by the Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers?
    a. Five State Standards
    b. Ten State Standards
    c. Eleven State Standards
    d. EPA Sewer Design Requirements

3. Infiltration into a gravity sewer system typically enters the pipe from which of the following?
    a. groundwater
    b. surface water
    c. both of the above
    d. none of the above

4. What is the typical minimum diameter of a manhole?
    a. 48 inches
    b. 60 inches
    c. 72 inches
    d. 84 inches

5. Manholes are recommended at which of the following?
    a. Changes in vertical alignment
    b. Changes in horizontal alignment
    c. Both of the above
    d. None of the above

6. Which of the following manhole cone sections has a vertical side for installation of steps?
    a. Concentric cone
    b. Eccentric cone
    c. Both of the above
    d. None of the above

7. How is the cover of a manhole set to ensure it matches the top of roadway surface?
    a. By carefully setting the cone section so the frame matches the roadway.
    b. By the use of adjusting rings between the cone section and the cover
    c. It's not important to have the cover match the roadway surface.
    d. None of the above.

8. How is the connection made between the pipe and the manhole?
    a. With a flexible boot
    b. Using non-shrink grout
    c. Either of the above can be used
    d. None of the above

9. What is the recommended spacing for vents on a sanitary sewer line?
    a. Every 400 feet
    b. Every 500 feet
    c. Every 600 feet
    d. Every 1000 feet
    e. All of these locations are equally desirable.

10. Which of the following is a common depth for a gravity sanitary sewer main?
    a. 5 feet
    b. 7 feet
    c. 11 feet
    d. 20 feet

11. What is the typical required minimum separation between a potable water main and a sanitary sewer main?
    a. 5 feet
    b. 10 feet
    c. 15 feet
    d. There is usually no minimum separation required.

12. What is the typical drop in invert elevation across a manhole?
    a. 0.0 ft
    b. 0.1 to 0.2 ft
    c. 0.4 ft to 0.5 ft
    d. 1.0 ft.

13. Which of the following is a common SDR rating for PVC gravity sewer pipe?
    a. 14
    b. 18
    c. 26 or 35
    d. 51

14. Which of the following materials are generally acceptable for sanitary sewers?
    a. Solid Wall PVC
    b. Profile wall polypropylene
    c. Vitrified clay
    d. All of the above are generally acceptable.

15. The bedding material under the pipe is most commonly what type of material?
    a. Granular
    b. Well compacted clay
    c. Loose silt
    d. Any of the above are commonly used.