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Feature

Keeping Your Landfill's Arteries Clear

How to prevent crushing and collapse of leachate collection pipes.

By Daniel P. Duffy

There are two primary types of pipe used in leachate collection systems: perforated polyvinyl chloride (PVC) or slotted/perforated high-density polyethylene (HDPE). Each type of pipe is subject to two types of failure modes: impact loads from vehicular and equipment traffic running over the pipe immediately after installation and static loads causing long-term buckling failure as a result of overburden weight from the overlying waste. Combining the pipe types with failure modes gives us the four pipe instability conditions examined by this article.

PVC pipes are rated by their pipe-wall thickness, which is described as the pipe's "Schedule." Schedule 40 (with a thinner pipe wall) and Schedule 80 (with a thicker pipe wall) are the most commonly used, though other Schedules are commercially available. "Schedule" does not refer to pressure classification. This would be inappropriate anyway, since the perforated pipe used to collect leachate provides gravity-flow pathways not

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pressure-flow mediums. Pipe-wall thickness increases with Schedule rating while relative pipe strength (a function of the ratio of the pipe's wall thickness to its diameter) decreases with increased diameter.

In landfill leachate collection applications, Schedule 40 is most commonly used except in cases where the depth of waste above the pipe is of exceptional thickness and overburden weight. Typical pipe diameters used in leachate application range from 4 inches to 12 inches (with 6-inch diameter being typical). Table 1 and Table 2 show a comparison between Schedule 40 and Schedule 80 pipes.

HDPE pipe is rated differently than PVC pipe, using a Standard Dimension Ratio (SDR) instead of a pipe schedule category. The SDR originated with the need to give the same pressure for all the diameters of the pipes rated with the same SDR. So HDPE pipes with the same SDR will have the same pressure rating whether they are 1 inch or 36 inches in diameter. Again, HDPE pipes (like PVC pipes) used in the collection of leachate do not transmit pressurized flows. However, this pressure capacity has an effect on a pipe's ability to resist buckling from applied loads. Common SDR ratings for HDPE pipes used in leachate systems include SDR-7, SDR-9, SDR-11, and SDR-13.5, with SDR-9 and SDR-11 being the most common. The diameters of HDPE pipes used in landfill leachate collection systems also range from 4 inches to 12 inches, with 6 inches being the most commonly used. This preference for a 6-inch diameter pipe, whether PVC or HDPE, is mostly a function of cleanup and pipe-jetting needs rather than pipe flow capacity.

The dimension ratio referred to by the SDR rating is the ratio between the pipe's nominal outside diameter and its pipe-wall thickness. An HDPE pipe with an SDR-9 rating, for example, will have an outside diameter 9 times greater than its pipe-wall thickness. So pipes with the lower SDR ratings have relatively thicker pipe walls and are proportionally stronger. Table 3 and Table 4 show a comparison between SDR-9 and SDR-11 pipes.

Both types of pipe are installed within a mounded bed of aggregate materials that serves two functions. First, the aggregate acts as a separation filter medium between the collection pipes and the adjacent sand of the leachate collection layer. Second, it provides a strong base that physically supports the pipe's structure. This is especially important for HDPE pipe, which together with the surrounding aggregate forms a pipe/soil structural system.

Static Loading Conditions

Two conservative assumptions are typically made when analyzing the dead load of overlying soil and waste on leachate collection pipes. First, the entire column of waste and soil directly over the pipe is assumed to be weighing on the pipe. In truth, the soil and waste overburden arches over the pipe at a certain height, distributing much of the overburden around and away from the pipes. This arching of waste and soil over the leachate collection pipes is conservatively ignored so that the load from the total depth of waste and soil can be applied to the pipe. Furthermore, the analysis used to determine the deflection on PVC pipes (the Modified Iowa Formula) usually assumes a maximum of 50 feet of overburden acting on the pipe.

Second, the analysis is confined to the worst-case situation (typically at the very center of the landfill) where waste and soil are at their thickest and collection pipes are at their deepest. Even if pipe collapse were to occur at this deepest point, the pipe's structural failure would not seriously impede its flow capacity over the majority of its length. However, applying the worst case over the entire pipe length results in a built-in factor of safety for the analysis.

The average in-place density of the overburden is approximately 130 lbs per cubic foot (1.75 tons per cubic yard). The thicknesses of the aggregate bedding layer are insignificant compared to the thickness of the overburden and are ignored for the purposes of computation. As a simplifying assumption, any portion of the proposed final cover system overlying the pipe will be assumed to have the same density as the rest of the overburden. Therefore, 100 feet of waste and soil overburden will apply 13,000 lbs per square foot, or about 90 lbs per square inch. Every linear foot of a nominal 6-inch diameter would have to withstand 6,500 lbs of dead weight.

Impact Loading Conditions

Live impact loadings are the result of vehicular and equipment movement over the pipes immediately after they are installed. In this situation, a leachate collection pipe typically buried under a 2-foot thick aggregate and sand collection layer (some states allow a 1-foot-thick layer). The 2-foot-thick layer of overlying aggregate has a typical unit weight of 120 lbs per cubic foot, resulting in a dead load of 240 lbs per square foot, or 1.67 lbs per square inch. This minimal dead load is added to the impact loading to make the total live load on the pipe.

The impact loading is derived from the H20 highway loading, which is based on a simulated 20-ton truck traffic and resultant impact. This impact loading decreases as the thickness of the cover overlying the pipe increases. Table 5 summarizes these loads.

With a minimum 2 feet of cover, the H20 impact loading is equivalent to 5.56 lbs per square inch or 800 lbs per square foot. With the static load from the overlying soil aggregate, the total live load on the pipe would be 7.23 lbs per square inch (5.56 = 1.67), or 1,040 lbs per square foot. A linear foot of a pipe with a nominal diameter of 6 inches would have to withstand a total dynamic load of slightly more than 500 lbs.

PVC Pipe Strength Characteristics

Assuming a deep (worst-case) landfill design, Schedule 80 PVC pipe would be preferred. Six-inch nominal-diameter Schedule 80 PVC has an inside diameter of 5.701 inches and an outside diameter of 6.625 inches. Pipe-wall thickness is therefore 0.432 inch. Pipe perforations are typically 0.375 inch in diameter and spaced in a double row with 6-inch spacing between perforations. The number of perforations per foot of pipe length is therefore four each. The modulus of elasticity of PVC is 420,000 lbs per square inch.

The bedding soil adjacent to the pipe usually consists of highly compacted (as a result of the weight of the overburden) coarse-grained soils having a modulus of reaction of 3,000 lbs per square inch. The maximum allowable pipe deflection from applied loads is no more than 7%. This provides a factor of safety of 4:1 against inverse pipe curvature (pipe failure).

HDPE Pipe Strength

As a nonrigid, nonpressurized pipe, the stability of the HDPE pipe should be considered as part of a soil/pipe system. The total design period for the HDPE leachate collection pipes/groundwater interceptor pipes is 30 years (conforming to a typical 30-year post-closure care period). Though the potential for equipment and/or vehicle impact loads is much greater during initial construction, the longer design period is conservatively assumed.

Typical leachate collection pipes are 6-inch nominal-diameter SDR-11 HDPE having an inside diameter of 5.421 inches and an outside diameter of 6.250 inches. Pipe-wall thickness is therefore 0.415 inch. Pipe perforations are 0.375 inch in diameter and spaced in a double row with 6-inch spacing between perforations. The number of perforations per foot of pipe length is four each. The modulus of elasticity after the 50-year design time is 28,000 lbs per square inch. The bedding soil adjacent to the pipe consists of highly compacted (as a result of the weight of the overburden) coarse-grained soils having a modulus of reaction of 3,000 lbs per square inch.

PVC Deflection Methodology
The vertical stress on PVC pipe as the result of waste overburden is estimated by the Modified Iowa Formula, which is derived from the following formula for applied vertical stresses on the pipe:

W = (Dw * H * OD) * (1 square foot / 144 square inches)
where,
W = Vertical stress on the pipe (lbs per inch of pipe length)
Dw = In-place density of the waste or soil (lbs per cubic foot)
H = Total waste or soil fill height (feet)
OD = Outside diameter of the leachate collection pipe (inches)

The estimated vertical stress is modified by the collection pipe perforations:

Wp = (W * 12) / (12 - (D * N))
where,
Wp = Modified Vertical Stress on the Pipe (lbs per inch of pipe length)
W = Vertical stress on the pipe (lbs per inch of pipe length)
D = Diameter of the pipe perforation (inches)
N = Number of pipe holes (each per foot of pipe length)
The pipe-wall thickness is determined as follows:
Tp = (OD - ID) / 2
where,
Tp = Pipe-wall thickness (inches)
OD = Outside diameter of the leachate collection pipe (inches)
ID = Inside diameter of the leachate collection pipe (inches)
Given the pipe-wall thickness, the pipe wall’s moment of inertia can be determined:
I = (Tp^3sup> / 12)
where,
I = Pipe-wall moment of inertia (inches4 per inch)
Tp = Pipe-wall thickness (inches)

This moment of inertia (resistance to bending) is the same for any rectangular cross section being bent along its middle axis (($b * h^3$) / 12). In the case of the pipe wall, the value b is the width of the rectangular cross section and is taken to be an arbitrary unit value of 1. The mid point of the pipe wall's rectangular cross section area is the pipe's mean radius halfway between it inside wall surface and outside wall surface. The pipe's mean radius is determined as follows:

r = 0.5 * ((OD + ID) / 2)
where,
r = Pipe mean radius (inches)
OD = Outside diameter of the leachate collection pipe (inches)
ID = inside diameter of the leachate collection pipe (inches)
Given the above information, the potential horizontal deflection of the pipe is determined by the Modified Iowa formula:
$X = (Dl * K * Wp * r^3) / ((Ep * I) + (0.061 * Es * r^3)$
where,
X = horizontal deflection (inches)
Dl = deflection lag factor (dimensionless, 1.25 to 1.50)
K = pipe bedding constant (dimensionless, typically 0.1)
Wp = modified vertical stress on the pipe (lbs per inch of pipe length)
r = pipe mean radius (inches)
Ep = PVC pipe modulus of elasticity (lbs per square inch)
I = pipe wall moment of inertia (inches 4 per inch)
Es = bedding soil modulus of reaction (lbs per square inch)

The two dimensionless factors, deflection lag and pipe bedding, are derived from empirical studies. The deflection-lag factor accounts for long-term soil consolidation at the sides of a flexible pipe and the resulting reduction of soil support. Since landfill leachate pipes must function at least until the end of the landfill's 30-year post closure care period, it is best to use the larger of the factor's potential value (1.5) when performing the calculation.

The bedding constant accounts for the supporting force applied by the pipe-bedding material on the pipe. The bedding constant is derived from the bedding angle (formed at the vertex of the pipe's center) and the points on its rim where the top of the bedding material surface intersects the pipe. The harder the bedding material the less the pipe settles into the bedding, which makes the bedding angle small. Soft bedding allows a pipe to settle more deeply, resulting in a wider bedding angle. Softer bedding materials are preferred over hard or rigid bedding. The bedding constant is shown in Table 6 .

The percentage of horizontal deflection is determined as follows:

$$X\% = X / (2 * r)$$

where,
X% = percentage of horizontal deflection (percent)
X = horizontal deflection (inches)
r = pipe mean radius (inches)

Any result that gives a deflection less than 7% is considered to be a stable PVC pipe design.

HDPE Buckling Methodology
The external soil/waste pressure on the pipe is estimated as follows:

$$Pt = (Dw * H) * (1 \text{ square foot} / 144 \text{ square inches})$$

where,
Pt = External Soil Pressure (psi)
Dw = In-Place Density of the Overburden (lbs per cubic foot)
H = Total Overburden Fill Height (feet)

The potential for wall crushing failure of the HDPE pipe is dependent upon the actual compressive stress:

$$Sa = ((SDR - 1) * Pt) / 2$$

where,
Sa = Actual Compressive Stress (psi)
SDR = Standard Dimension Ratio (dimensionless, 11)
Pt = External Soil Pressure (psi)

The factor of safety against wall crushing is determined by dividing the pipe’s compressive yield strength by the actual compressive stress:

$$FSc = Ys / Sa$$

where,
Fsc = Factor of Safety against Wall Crushing (dimensionless)
Ys = Compressive Yield Strength (psi)
Sa = Actual Compressive Stress (psi)

The potential for long-term wall buckling pipe failure is dependent upon the pipe/soil system’s critical buckling pressure:

$$Pcb = 0.8 * (E' * Pc)1/2$$

where,
Pcb = Critical Buckling Soil Pressure at the Top of the Pipe (lbs per square inch)
E' = Soil Modulus (calculated as the ratio of soil pressure to vertical soil strain at a specified density). For soil pressure greater than 4,000 lbs per square inch and a compaction of 90% of Standard Density, the soil strain is 2% and E' = Pt /2%.
Pc = Hydrostatic, Critical Collapse Differential Pressure (lbs per square inch)

Table 7 provides a modulus of elasticity for pipe bedding soils (lbs per square inch).

The hydrostatic, critical collapse differential pressure is calculated as follows:

Pc = (2.32 * E) / (SDR3)
where,
E = The HDPE stress and time dependent tensile modulus of elasticity (28,000 lbs per square inch after 50 years for an actual compressive stress of Sa = 200 lbs per square inch)
SDR = standard dimension ratio (dimensionless, 11)

The factor of safety against wall buckling is determined as follows:

Fsb = Pcb / Pt
where,
Fsb = factor of safety against wall buckling (dimensionless)
Pcb = critical buckling soil pressure at the top of the pipe (psi)
Pt = external soil pressure (psi)

The percentage of ring deflection is based upon strain for a given SDR and is calculated as follows:

Y% = dY / OD
or
Y% = 0.25 * e * SDR
where,
Y% = Percentage of Ring Deflection (percent)
dY = Vertical Deflection (inches)
OD = Outside Diameter of the Pipe (6.25 inches for 6 inch SDR-11 HDPE)
e = Tangential Strain in the Surface of the Pipe Ring (dimensionless, conservatively estimated at 0.01)

SDR = Standard Dimension Ratio (dimensionless, 11)

The factor of safety against ring deflection failure is determined as follows:

FSr = Y% / es
where,
Fsr = Factor of Safety against Ring Deflection Failure (dimensionless)
Y% = Percentage of Ring Deflection (percent)
es = Adjacent Soil Strain (for soil pressure greater than 4,000 lbs per square inch and a compaction of 90% of Standard Density, the soil strain is 2%)

Advantages and Disadvantages
So which type of pipe should be used? Which is more rugged and apt to survive under long-term stresses for the duration of the landfill's operating lifetime and post-closure care period? Actually, both work well in terms of structural stability provid

d they are not placed in extreme-load conditions or are over-designed (and too expensive) for situations where loads are minimal. Even then, derivatives of the two main types of leachate collection pipes can be used. In extreme-load conditions, truss pipe (whose wall is hollow and reinforced with continuous triangular trusses like a roofline) can be used. In light-load conditions, corrugated HDPE pipe with minimal bedding is acceptable.

In either case, the landfill operator must remember that applied external loads acting in a single downward direction is not the same as high-pressure containment radiating equally in all directions along the pipe. Pipe collapse and wall buckling are not the same failure mechanism as pressure bursting, so different rules apply.

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