Proceedings of Heap Leach Solutions 2022
October 16–18, 2022, Sparks, USA

On the Use of Buried Pipes in Heap Leach Facilities

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Abstract

Heap leach facilities can place very high loads on pipes that are constructed into their drainage systems. With heaps up to 150 m (500 ft) or more in height currently in operation, the integrity and long-term survivability of these pipes should be of paramount concern to heap owners, operators, and designers.

In typical civil engineering applications, buried pipes receive significant, prescribed mechanical compaction efforts. Unlike their civil engineering counterparts, drainage pipes in heap leach facilities do not normally receive this mechanical compaction effort. This paper provides some background and guidance regarding the design, construction, and survivability of pipes buried in heap leach facilities.

Heap leaching basics

The design of a heap leach facility requires several types of engineering specialists, the description of which is beyond the scope of this paper. The engineering firm that completes this design is usually termed the “design engineer”. The design engineer prepares the construction drawings and technical specifications for the project, among other things. The technical specifications are essentially instructions to a contractor, telling them exactly how they are expected to complete their work.

During construction of a heap leach facility, it is common to employ an independent firm to help assess whether the construction is being completed in accordance with the design. This service is sometimes referred to as construction quality assurance (CQA), quality assurance (QA), quality control (QC), or quality control/quality assurance (QC/QA). The design engineer’s company commonly performs this work. Sometimes the contractor is expected to provide their own QC work.

In order for the retention and recovery of the enriched solution to be possible, a system including lining and drainage is constructed at the base of the ore pile, prior to placing the ore. Following some re-contouring of the area to receive ore, a layer of material is placed to assist in retaining the solution. This layer is sometimes referred to as “clay”. The term “clay” has a very specific meaning to geoscientists such as geotechnical engineers, who commonly lead the design of heap leach facilities. The actual goal of that layer is to achieve a desired permeability. Permeability indicates the rate an aqueous (predominately water) solution will pass through the soil. Geotechnical engineers have come to refer to this clay layer as a low hydraulic conductivity soil layer (or LHCS layer) because the layer may have soil types other than clay as its key component. Hydraulic conductivity, in this case, means the same thing as permeability. In some cases, the LHCS layer may be replaced in part or in whole by a geosynthetic product known as a geosynthetic clay liner (GCL). The design engineer must take great care when designing with a GCL, due to the potentially low internal shear strength of the GLC, which may create slope stability considerations.

Immediately above this clay layer is typically placed a geomembrane. A geomembrane is in a family of geosynthetic products. In this case, the geomembrane comes in a roll and is unrolled over the clay layer. A geomembrane is typically made of some form of specialty plastic that is manufactured to withstand the sometimes-harsh environment in which it may be deployed at a mine site. High-density polyethylene (HDPE) is currently among the most common plastics used in geomembranes for heap leach facility construction. Once unrolled, the geomembrane is "welded" together to form a tight seal, greatly limiting the amount of enriched fluid that can escape from the containment of the heap leach facility. The welding is accomplished by various means that essentially cause the localized melting of one layer of geomembrane into another layer.

To facilitate the recovery of the enriched solution from the heap leach facility, a drainage layer is constructed on top of the geomembrane. This layer is sometimes referred to as the overliner. This layer consists of highly permeable sands and gravels, and normally also has a network of slotted pipes to assist in more rapidly removing the enriched solution from the heap leach facility. The design of this layer is very specific to the project materials, but normally varies between 0.5 m (18 inches) and 0.9 m (3 feet) in thickness.

The sands and gravels used for the overliner often have to be processed in order for them to comply with the project's technical specifications. While some projects have naturally occurring materials that comply with the project requirements, other projects will have to improve their materials, either by crushing their material into a smaller product, or screening it to remove some materials, or a combination of crushing and screening. In these cases, specialty crushing and/or screening plants are used.

Occasionally there are other layers involved in a heap leach facility. The construction of some of these components may be completed by one or more independent contractors.

Pipe installation and compaction

The practice of installing pipes in civil engineering projects differs significantly from the practice of installing pipes in heap leaching projects. Pipes installed in heap leach facilities are often buried very deeply, while those in civil engineering applications are usually quite shallow. For example, the Plastic Pipe Institute (2009) indicates that for a pipe surrounded by crushed rock and buried by dumped fill can only be buried to a maximum depth of 6.4 m (21 ft). ADS (2016) indicates that pipe can be buried up to a depth of

11.3 m (37 ft), depending on the pipe diameter and backfill characteristics. Those limitations on burial depth would never be useful in heap leaching projects. A discussion of these practices is provided to expand on this matter.

Pipe installation in civil engineering projects

The piping manufacturer company Advanced Drainage Systems (ADS, 2018) provides a good source for guidance on adequate depth for pipe burial when it is subject to trafficking. For example, they state that a 0.3 m (12-inch) cover is adequate to protect a 0.3 m (12-inch) diameter pipe. Table 1 from that ADS publication is reproduced below.

Table 1: Table of minimum pipe burial depths (from ADS, 2018)

Pipe inside diameter		Minimum cover	
mm	in	m	ft
100	4	0.3	1
150	6	0.3	1
200	8	0.3	1
250	10	0.3	1
300	12	0.3	1
375	15	0.3	1
450	18	0.3	1
600	24	0.3	1
750	30	0.3	1
900	36	0.3	1
1,050	42	0.3	1
1,200	48	0.3	1
1,350	54	0.6	2
1,500	60	0.6	2

That specification is found in the *ADS Drainage Handbook*. The handbook provides instructions on placing and compacting pipe backfill for the lower half of the pipe and for its upper half. For the lower half, ADS recommends placing the fill in 4- to 6-inch-thick lifts and compacting it in accordance with product specific guidelines listed in their appendix. ADS indicates that this zone, “is the most important since it is this layer that provides the pipe with support against the soil and traffic loadings”. For the backfill around the upper one-half of the pipe, ADS indicates, “this area of the backfill anchors the pipe and ensures that loads are distributed as evenly as possible into the haunching [lower one-half of the pipe]”. Refer to Figure 1 for illustration of the haunch of a pipe. Material placement and compaction guidelines are provided. ADS indicates that these zones are to be compacted to a minimum of 90% of standard Proctor density, indicating that a considerable degree of compaction is needed. The Plastic Pipe Institute (2009) states, “Do not allow rocks or other hard objects in the vicinity of the buried [pipe]”.

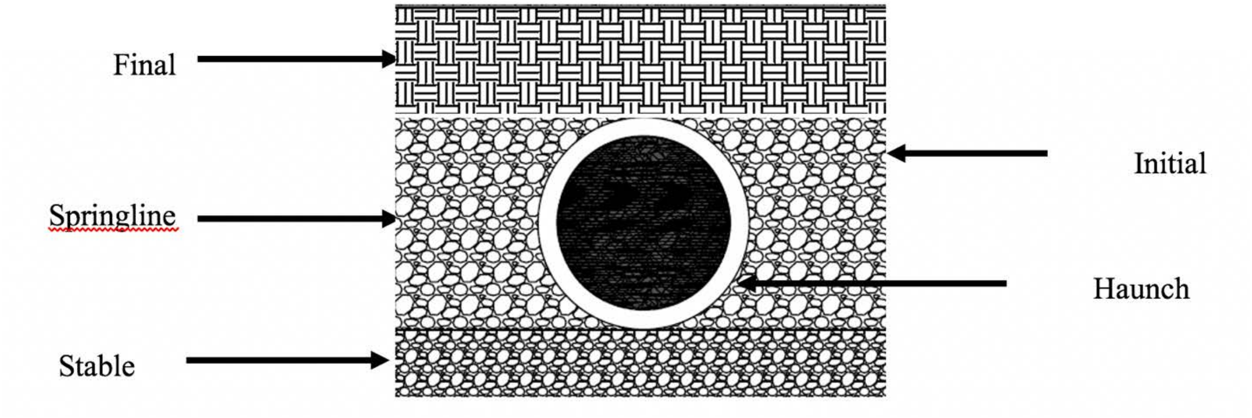

Figure 1: Illustration of pipe burial showing terminology (modified after ADS, 2016)

Pipe installation in heap leaching projects

In a heap leach facility, pipes are typically placed on the top of the lining surface (for example on the geomembrane liner). Once positioned and (potentially) stabilized in place, low ground pressure equipment is used to spread overliner onto the pipe. At this point, it is very important that an observer visually assesses whether the overliner material is flowing freely, and into the haunch area of the pipes. If the overliner is too wet, the material is unlikely to flow into this area. It is imperative that dry material is used so that the haunch is adequately supported.

The material surrounding the pipes is typically not compacted. This is because such compaction would likely damage the geomembrane, and the compaction would reduce the permeability of the overliner. Table 2 provides a summary of some of the differences between pipe placement in civil applications versus in mining applications.

Table 2: Summary of differences in pipe placement in civil versus mining applications

Civil application	Heap leaching application
Install is in a well-formed trench	Install is on an open surface
Middle one-third of bedding should be loosely placed	Bedding layer is uniformly compacted
Compact fill into haunch in prescribed layers	Ensure the fill flows beneath the haunch
Remainder of embedment zone placed and compacted in layers	Material is not compacted
Compactive effort depends on soil type	Material is not compacted

The industry practice for placement of overliner is essentially to deliver the overliner using the least amount of equipment trafficking as possible/practicable so that compaction of the overliner material is minimized. This is done by identifying delivery paths ("roads") for the haulage equipment (trucks) to deliver the overliner to the pad. From there the material is spread into place using low ground pressure dozers. The roads are dedicated trafficking areas for trucks delivering overliner to the pad. The thickness of the overliner is increased along the length of the roads in order to better protect the liner/lining and drainage system and to reduce the amount of crushing of the overliner. Once all the overliner delivery is complete, the additional overliner along the roads is removed, and the remaining material once beneath the road is ripped, if necessary. This construction sequence is chosen to minimize damage to the liner/lining and drainage system and to reduce compaction to the overliner material.

The use of a test fill is a proof of principle in that it is a field-scale demonstration of the proposed construction method. In the case of a heap leach facility, a test pad would be used to assess the integrity of the lining/liner and drainage system when subjected to the forces applied by the contractor's proposed equipment. It is common to document how the test is carried out, indicating the number of passes of each piece of equipment passing over the test fill, and often test fills of various thicknesses of overliner are included. It is important to know how many times each piece of equipment has passed over the test fill, as pipes and other buried items may survive a limited amount of equipment passes, but not a greater number of passes.

A test fill is especially important in understanding how the pipes will perform when they are buried in a relatively shallow state, i.e., when the overliner layer is being constructed and equipment is trafficking over the pipes.

Deeply buried pipe

As discussed, pipes installed in heap leach facilities are very often installed to be at much greater burial depths than is advised by pipe manufacturers. In the following sections we will explore this further.

The Ohio experiment

In the Ohio experiment, Sargand et al. (2001) buried HDPE and polyvinyl chloride (PVC) pipes at depths of 6.1 and 12.2 m (20 and 40 ft). Soil pressure cells were installed above the pipes at various depths. One of the soil pressure cells was installed approximately 25 mm (1 inch) above the pipes. The test results clearly demonstrated that the vertical earth pressure was normal except near the pipe, where there was a significant reduction in the pressure. Although the paper by Sargand et al. (2001) has the phrase "deeply buried thermoplastic pipe" in the title, their pipe burial depths are relatively shallow for heap leach facilities. They offer very little in the way of explaining why the vertical overburden pressure decreases close to the pipe.

Sargand and Masada (2003) provide additional analysis. They state that "the soil pressure over the pipe is influenced by the vertical settlement ratio between the pipe and the adjacent soil column at a horizontal surface above the pipe." This concept was first explained by Marston and Anderson (1913). They indicate that "frictional resistance relieves part of the vertical pressure [to the pipe] near the sides of the ditch [walls], so that at the level of the top of the pipe the vertical pressure of the filling material is much heavier in the middle of the ditch than at the sides". And "hence the pipe must be strong enough to carry safely the entire weight of the ditch filling materials above the top of the pipe less the friction of the filling against the sides of the ditch". Since pipes in heap leach facilities are rarely installed into excavated trenches, this case holds no merit for our application. Marston and Anderson (1913) provide no real discussion of arching.

Terzaghi's theory of arching

According to Terzaghi (1943), "if one part of the support of a mass of soil yield while the remainder stays in place the soil adjoining the yielding part moves out of its original position between adjacent stationary masses of soil. The relative movement within the soil is opposed by a shearing resistance within the zone of contact between the yielding and the stationary masses. Since the shearing resistance tends to keep the yielding mass in its original position, it reduces the pressure on the yielding part of the support and increases the pressure on the adjoining stationary part. This transfer of pressure from a yielding mass of soil onto adjoining stationary parts is commonly called the arching effect, and the soil is said to arch over the yielding part of the support".

Terzaghi (1943) went on to explain this with an analogy. In the analogy, there is a layer of sand above a solid base. In the center of the solid base is a trap door (Terzaghi refers to it as a "strip", rather than as a trap door). If the trap door is opened slightly and slowly, sand in the immediate vicinity of the trap door will subside into the newly created void. Frictional forces within the remaining sand mass resist full movement of sand into the void. The reduction of stress on the trap door is balanced by an increase in stress elsewhere on the solid base. In the case of a deeply buried pipe, if the crown of the pipe yields slightly (i.e., it acts as Terzaghi's trap door), the stresses of the overlying soil are shed to the surrounding materials, and the vertical stresses on the pipe decrease toward zero. This is Terzaghi's theory of arching in practice and this explains why there was a reduced vertical stress near the pipe crowns in the Ohio experiment. The crowns on those pipes buckled inward slightly, acting as Terzaghi's trap door. Soil above was stabilized due to frictional forces, and the reduction of stress on the crown of the pipes was shed to the soil surrounding the pipes. Yielding of the crown is also referred to as ring deflection (e.g., Lupo, 2005).

It is because of the stress-relieving effect of soil arching that pipes can survive deep burial in heap leach facilities. That is, if they are otherwise well-constructed.

Pipe integrity

The theorical performance of buried flexible pipes was published by Burns and Richard (1964) for an elastic circular pipe deeply buried in an infinite elastic medium subjected to horizontal and vertical loading. Moser (1997, in Suleiman, 2002) stated that the greatest shortcoming of the Burns and Richard solution is its assumption of double symmetry. That is, the assumption that the soil-pipe system is symmetric about horizontal and vertical axes. In this solution, no assumption was made (or needed) for the pressure distribution around the pipe. Smith (2004) reported that the Burns-Richard solution was derived from classical civil engineering applications with maximum burial depths of 5 to 20 m beneath rigid structures such as pavements or buildings. Thus, for deeply buried pipes in a heap leach facility, the Burns-Richard solution, as it stands, is of little use.

As discussed in Rosemont (2010) a series of large-scale laboratory vertical load tests was conducted on a 600 mm (24-inch) diameter corrugated plastic tubing (CPT) pipe manufactured by Advanced Drainage Systems Incorporated (ADS). The testing was conducted at the U.S. Bureau of Reclamation (USBR) in Denver, Colorado using a large-scale cross-section of a heap leach pad liner system including soil liner, geomembrane, protective soil, a drainpipe, and a drainage layer. The testing was conducted to evaluate the performance of the pipe under the loading conditions expected on a heap leach pad stacked to a height of 170 m (560 ft). The testing indicated a deformation of 130 mm (5.1 in), approximately 21%, at 140 m (460 ft) and a vertical deformation of 178 mm (7.02 in), approximately 29%, at 170 m (560 ft). As discussed by Lupo (2005), non-pressurized HDPE pipes appear to suffer serious deformation and buckling if the crown deflection exceeds 20 percent. Lupo (2005) indicates that a maximum crown deflection of 15 percent can be used for design if the reduction in flow area due to crown-deflection is tolerable. In Lupo's opinion, the degree of crown buckling observed in the USBR tests would not be advisable.

Lupo (2005) discusses the shortcomings of the Burns-Richard approach. Lupo states that the solutions presented by Burns and Richard, and as well by Höeg (1968, in Lupo, 2001) assume both the properties of the pipe and the soil are constant and that they are linear elastic. As stated by Lupo, these simplifications limit the usefulness of these equations for flexible pipe design, since both the pipe and ore materials have non-linear behaviour under compression. Lupo (2001) provides a modified version of the Burns-Richard equation to account for non-linear ore and pipe behaviour as well as arching.

As an alternative, one could utilize numerical modeling of buried pipe, as discussed by Saadeldin et el. (2015).

Chapter 8 of the Plastic Pipe Institute's manual (2009) discusses Florida's Department of Transportation 100-Year Service Life Protocol, which was "to ensure that pipes are manufactured with [of corrugated HDPE pipes manufactured with virgin] materials sufficient to prevent brittle failures and with sufficient antioxidants to prevent chemical failures, prior to 100 years of service". This protocol can be used if one wishes to calculate the service life of a pipe; however, in the author's opinion, most pipes manufactured by reputable pipe venders will have a service life longer than the life of a heap leach facility.

Other advice

Although it has not been discussed, so-called "single wall" corrugated pipes have little-to-no application as buried pipes in heap leach facilities. Buried pipes should either be the dual-wall variety (smooth interior, corrugated exterior) or HPDE pipes with a considerable wall thickness. Coupling of pipes should always follow the manufacturer's recommendations, and when using bell and spigot pipes, it is very important to ensure that the male pipe is inserted completely into the female pipe.

Also, it can be very beneficial to carry out camera inspections of pipes. This will tell you if the normal soil arching is occurring or whether excessive deformation is taking place. A photograph of such a camera inspection is provided in Figure 2.

Figure 2: Photograph of camera being used for pipe inspection

Another matter pertains to large-diameter pipes. There is a tendency for designers to indicate a locally thick zone of overliner being placed over larger-diameter pipes. The other, lesser chosen, option is to install these pipes in a trench. Not only does this lead to a simpler overliner placement operation, but if installed in trenches, the effects of arching are improved for these larger-diameter pipes. This concept is illustrated in Figure 3.

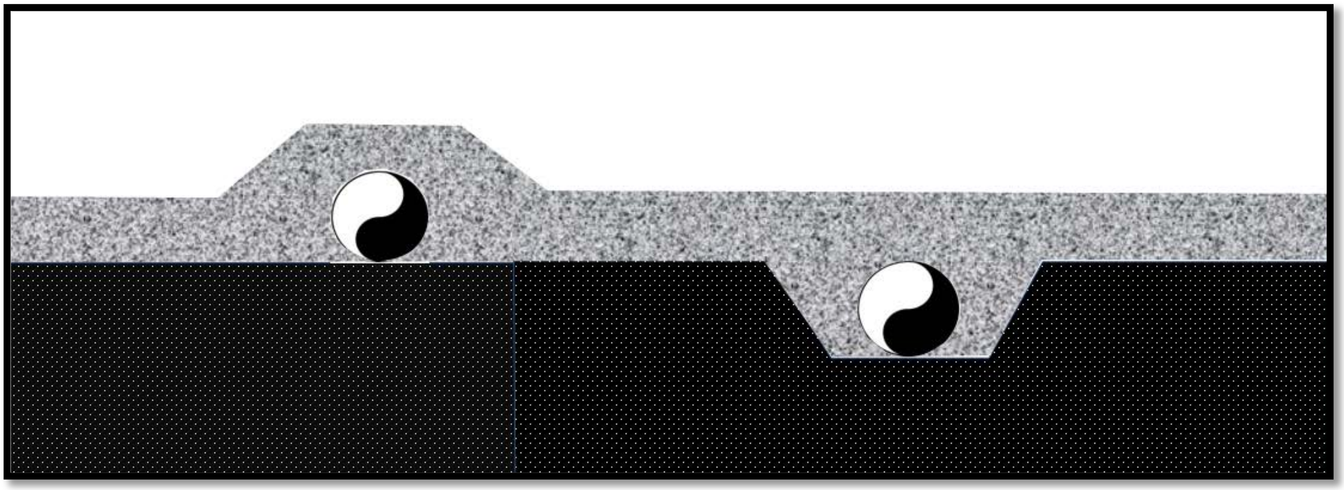

Figure 3: Illustration of large-diameter pipe placement options, mounded versus trenched

And one final word on the placement of pipes running in parallel. Such pipes should be placed far enough apart to allow the overliner to flow into the haunches of each pipe, which is at least somewhat dependent on the properties of the overliner.

Conclusion

As has been discussed, pipes installed in the drainage layers of heap leach facilities are typically buried much deeper than is advised by the pipe manufacturers, and much deeper than in most civil, non-mining applications. Probably the most important factor in constructing a pipe in a heap leach facility is to make sure the fill material (usually overliner) surrounding the pipes is dry and granular, and that it flows freely into the haunch of the pipe. This provides support for the lower half of the pipe and allows soil arching to take place. If the fill is not dry, or if the work is taking place during a precipitation event (be it rain or snow), all backfilling operations should be halted.

Since the cross-sectional area of the pipe will be reduced as arching occurs, the designer should take this into consideration when making pipe flow calculations. An area loss of around 50% is often assumed in order to be conservative.

Lastly, it can be very beneficial to carry out camera inspections of pipes. This will show whether the normal soil arching is occurring, or whether excessive deformation is taking place.

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