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Non-environmental surface (liquid) impoundments

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During a recent legal case, I had the opportunity to re-read *Construction of Linings for Reservoirs, Tanks, and Pollution Control Equipment* by William B. Kays, one of the early texts in the field of liquid containment design. I felt it would be beneficial to reacquaint *GFR's* readers with many of the concepts contained in this book, which is the result of one man's career in the construction of conveyances and reservoirs to transport and contain all description of liquids. It is required reading for designers and regulators alike.

Given the limited space available in this column, let's focus on understanding the role of underdrains in surface impoundments. Understanding the role of a component is clearly the first step in the design process. To understand the role of the underdrain, we must realize the difference in design philosophies between two important categories of surface impoundments lining systems: first, zero leakage liners that hold liquid constituents harmful to the environment, and second, reduced leakage liners that dramatically limit liquid loss but do not eliminate it. The first category is environmental impoundments typically associated with containment of liquids with significant Resource Conservation and Recovery Act (RCRA) or Toxic Substance Control Act (TSCA) constituents that legally cannot be allowed to migrate to the underlying groundwater. In these impoundments, the underdrain is generally referred to as a leakage detection system that collects the liquid passing through the upper or primary liner to limit the head acting on a lower or secondary liner. In this way, the underdrain reduces the leakage through the multiple liner system. The second category usually refers to impoundments for potable water. Here, the underdrain must drain liquid from beneath the liner to prevent accumulation of the liquid and potential whaling of the liner. Such underdrains act similarly to septic fields and actually assist the drainage of leakage to the groundwater.

A previous column (Richardson and Halse, 1999) focused on environmental or zero-leakage impoundments, so this column will extend the discussion to reduced leakage impoundments. Generally, these are very large reservoirs designed to contain many millions of gallons of potable water at a site where the natural subgrade would have a large seepage loss. In addition to a geomembrane liner, such reservoirs may be provided a floating geomembrane cover to limit evaporative water loss. **Photo 1** shows a large reservoir in southern California that is equipped with both a geomembrane liner and a floating cover. Here the "non-environmental" geomembranes are designed to reduce the seepage-related loss of the water and not to protect the underlying groundwater.

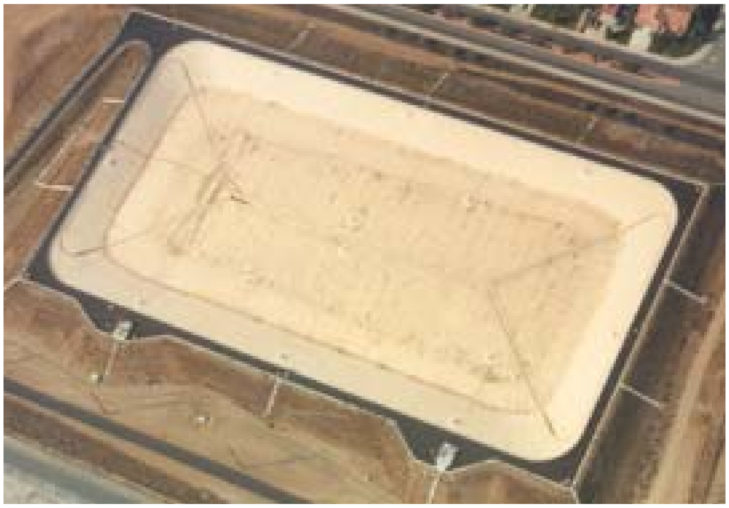

***Photo 1**. A large reservoir in southern California equipped with both a geomembrane liner and a floating cover.*

Design considerations

Non-environmental liner systems generally consist of a single geomembrane liner overlying a natural or constructed underdrain system. Key design considerations for these liner systems include the following items:

- Protection of the liner if future clean out of the reservoir is anticipated.
- Evaluation of the anticipated leakage rate for the liner system.
- Evaluation of the underdrain capacity.
- Evaluation of "whaling" considerations related to water leakage or gas, if applicable.

While simple, each one of these considerations has some significant differences from their application to environmental impoundments.

Protection of liner

***Photo 2**. Fabri-form protected liner in an environmental pond.*

While more common in environmental impoundments that accumulate sludge, the designer may be faced with a water influent that contains suspended solids, e.g. silt, that will settle to the reservoir floor and eventually require removal. The protective layer differs from the leachate collection/operational covers placed over environmental liner systems, since they are not designed to collect liquid and are commonly placed only on the floor of the reservoir. The liner protection system generally includes a nonwoven geotextile immediately over the geomembrane to act as a cushion, and then a layer of soil or manufactured block. Alternative protective systems include fabriform, as shown in **Photo 2**. Design guidance on the geotextile cushion can be obtained from previous *GFR* columns (Richardson 1996, Richardson and Johnson 1998). In general, a 12 ounce/yd^2 nonwoven will be adequate for protection of most liner systems with all but the coarsest of stone cover. Overly plastic soils should be avoided for use as protective cover since they require too much compaction effort and can swell to the point at which they no longer have sufficient strength to provide protection. Note that the protective cover layer also serves as a ballast layer that may be important in the "whale" evaluation.

Evaluation of leakage rate

Non-environmental impoundments are commonly constructed using flexible geomembranes not commonly employed on environmental applications. Such flexible liners include materials like PVC, hypalon, and XR-5. Leakage of the water through a liner can occur in two ways: first, by diffusion through an intact or "perfect" liner, and second, through penetrations related to defects. The flow through a "perfect" liner system occurs due to a diffusion process quantified using Fick's first law (see Lord and Koerner, 1984). **Table 1** presents a summary of diffusion rates (water vapor transmission per ASTM D814-55) of water through various geomembranes. Note that 1 gram/m^2/day is approximately equal to 1.07 gal/acre/day. In general, the diffusion rate of water through typical geomembranes is essentially zero for design purposes.

Geomembrane	**Hypalon**	**CPE**	**HDPE**	**PVC**
Diffusion Rate gram/hr/m^2	0.11	0.43	0.017	3.0

TABLE 1. WATER DIFFUSION RATE FOR COMMON CHARACTERISTICS

The low diffusion rates of water through geomembranes clearly show that leakage will be the result of defects in the liner system. These impoundments differ from landfills in the following key design considerations: first, the soils underlying the geomembrane are generally very permeable; second, the head greatly exceeds the 30-cm limit in landfills; and third, the geomembrane may have the potential to float or "whale" if gas or water accumulate beneath it. These design considerations clearly illustrate the difference between a landfill liner and liners in non-environmental surface impoundments.

As previously discussed (Richardson and Halse, 1999), the profession is fortunate that Dr. J.P. Giroud has committed a significant portion of his life to rigorously defining the performance of liner systems under a wide variety of field conditions. With respect to non-environmental surface impoundments, three solutions are of particular interest: first, flow through a defect with a free-draining subgrade, e.g. Bernoulli equation (J.P. Giroud 1984), Rate of Liquid Migration Through Defects in a Geomembrane Placed on a Semi-Permeable Medium (J.P. Giroud, et al. 1997a), and Liquid Migration Through defects in a Geomembrane Overlain and Underlain by Permeable Media (J.P. Giroud, et al. 1997b). The second solution models our liner without a protective cover, the third with a protective cover.

Assuming that soils adjacent to the defect are sufficiently free draining that they do not impede the flow of liquid through the defect, the leakage rate is given by Bernoulli's equation for free flow through an orifice as:

$$Q = 0.6\, a\, (2\, g\, h)^{1/2}$$

Where Q is the flow rate (m^3/sec), a is the area of the defect (m^2), g is acceleration due to gravity (9.81 m/s^2), and h is the head of liquid on top of the geomembrane (m). Fortunately, Giroud has quantified "free draining" for both overlying and underlying soil layers in contact with the geomembrane. The limiting free drainage permeability is a function of the size of the defect and head acting on the liner. Giroud has defined "practical" limits for minimum free drainage permeability as follows:

$$K_{om} = \frac{150\, d^2}{h^{3/2}}$$

$$K_{um} = 1000\, d^2$$

where K_{om} is the permeability of an overlying material and K_{um} is the permeability of an underlying material.

If the permeability of soil adjacent to the geomembrane does not satisfy the above permeability criteria, then the flow restriction provided by the soil must be accounted for. **Figure 1** provide Giroud's solution for a 1 cm^2 defect in a geomembrane underlain by a flow restricting soil layer. Note that the depth of liquid is limited to 3 m and t_{um} represents the thickness of the underlying soil layer. **Figure 2** provides Giroud's solution for a 1 cm^2 defect in a geomembrane overlain by a flow restricting soil layer. Note that the depth of liquid is not limited to 3 m.

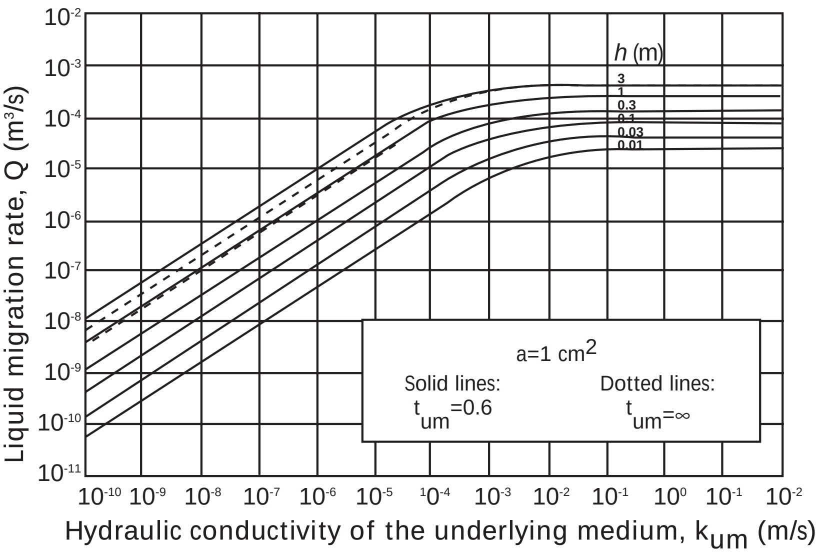

Figure 1*: Rate of liquid migration through a defect having a diameter d = 11.284 mm (i.e., a surface area of 1 cm^2).*

The 1 cm^2 defect has become a defacto design tool since we commonly related observed leakage rates a being equivalent to leakage from "X" number of 1 cm^2 defects. For landfill liner, I assume that 8 to 10 of the 1 cm^2 defects remain when a good CQA program is used and after the collector system is placed over the geomembrane. Lacking leakage data for non-environmental impoundments, it is reasonable to assume this same number of defects in such reservoirs unless supplemental field defect detection efforts are made. Such supplemental field efforts include electrical leak surveys, conductive geomembranes, etc. to ensure detection of the smallest of defects. Hydrostatic testing may be possible on smaller impoundments but factors such as the warming of the test water, evaporation, and the accuracy of a typical elevation measurements may limit the true meaning of such a test.

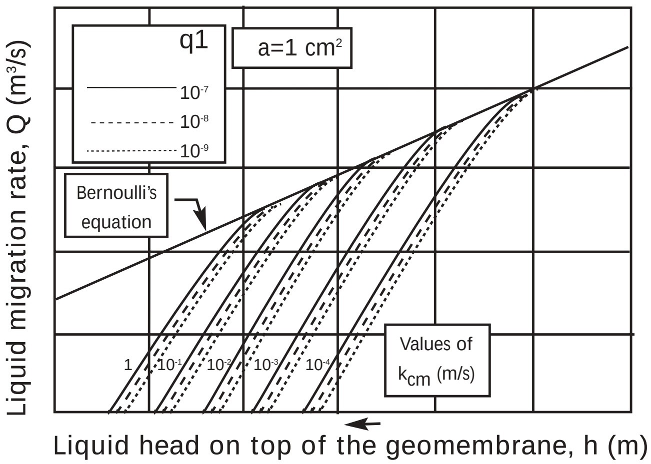

Figure 2*: Graphical solution of Equation 16 for a geomembrane defect having a surface area of 1 cm^2.*

Underdrain system

Free drainage of leakage away from the liner system is important to minimize the accumulation of water immediately beneath the liner. This is particularly true when using geomembranes such as polyethylene, which float in water. The maximum drainage rate of the subgrade can be conservatively estimated by assuming a unit vertical flow gradient such that the flow velocity is approximately equal to the permeability of the subgrade. This assumes that the leakage rate is small to isolate the subgrade from the head acting on the liner system. **Figure 3** presents the ratio of drainage capacity to leakage for a range of subgrade permeability assuming 10 defects per acre, a 3-m head, and no overlying soil layer. This ratio or factor of safety decreases with decreasing permeability of the subgrade. This safety factor actually indicates the degree to which the geomembrane liner system is reducing water loss. Remember that these non-environmental linings are constructed only when the permeability of the subgrade is large and seepage is excessive. Thus, many reservoirs constructed with adequate service protection for the liner may not require supplemental underdrains based on typical leakage. However, protection of the liner is essential, since a single major defect could eliminate this apparent surplus drainage capacity. Unforeseen saturation of the subgrade due to a period of heavy rain, raising water table, biofouling of the subgrade etc. could also eliminate the apparent subgrade drainage potential.

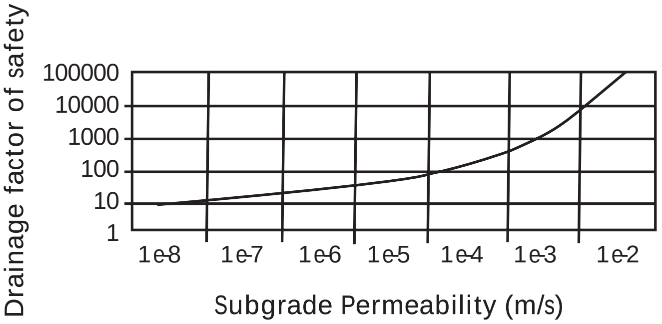

Figure 3*: Subgrade drainage factor of safety.*

In spite of the apparent large drainage factor of safety provided by the natural subgrade, most non-environmental liners are constructed with a underdrain that consists of:

- A blanket interceptor to intercept all water behind the liner,
- Perforated collector pipes to drain the interceptor,
- A filter to prevent subgrade erosion,
- Non-perforated conveyor pipes to carry the collected water to a
- Disposal area.

Kay’s feelings regarding underdrains is clearly seen in the following quote:

“Critical facilities with compacted earth linings should generally be protected with some type of underdrain system similar to that described in Chapter 2. In recent years, the procedure of designing underdrain systems has often been slighted with disastrous results. This practice has become rather widespread because of a lack of understanding of the basic principles involved by owners and other inexperienced persons who attempt to bypass the services of a competent, trained, and experienced soils engineer. The underdrain is a very important safety backup system that should be considered as independent of the lining.”

Design and use of a proper underdrain will eliminate the potential for whaling, even when “floater” geomembranes are used without a ballast layer. Such underdrains also provide a means of removing any gas that may be present due to organics in the subgrade or leakage. Both Kay’s book and Giroud were vocal in the early ’80s, dispelling the myth that geomembranes don’t leak.

Whaling considerations

The designer must be aware of whether the geomembrane being used to line an impoundment is a “floater;” i.e., polyethylene, or a “sinker,’” i.e., PVC, when evaluating the potential for whales. Geomembranes that are floaters require a functional underdrain or ballasting to prevent water from seeping under the lining and lifting it. I have repaired leachate ponds that were designed using a “composite” liner that included the proscriptive 60-mil HDPE and two feet of 10^{-7} cm/sec clay liner with **no** ballasting. While a very effective system for solid waste, this composite liner system requires ballasting to prevent leakage from simply lifting the HDPE liner off the clay when used for surface impoundments.

When “sinker” and “floater” geomembranes are used, the designer must ensure that no gas can accumulate beneath the liner. Such gas may be caused by the decay of organics within the subgrade or the liquid itself. An effective underdrain will also remove such gases. “Sinker” liners have also whaled when uplift forces caused by the attachment of flow baffles to the liner and due to the suction from aerators. External forces on all liners must be carefully evaluated to ensure that whaling is prevented.

Summary

Since Kay’s book is no longer in print, you will have to work to find a copy. But the effort will be greatly rewarded. Our prescriptive liner world pales in comparison to the creative period that Kays was privileged to work in. Back when men were men and your success was based on the quality of your work and not your ROI for investors, these men created our field using engineering principles and not legal descriptions. The author appreciates the review and comments provided by Rick Taylor of Serrot and Ian Peggs of I-CORP INTERNATIONAL Inc.

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