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Multi-Layer Closure Cover Stability and Infiltration

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Abstract

The purpose of this article is to demonstrate that flexible membrane liners (FMLs) are seem ill-suited for use as a barrier layer on steep slopes, especially in areas of high seismicity, such as California. The low frictional resistance of the materials used in the construction of FMLs increases the likelihood of failure (slippage) at the interfaces between these materials and the other cover components. A compacted clay layer, if carefully designed, constructed, and maintained, may provide a more optimal combination of stability and impermeability.

Introduction

Flexible membrane liners (FMLs) have for years proved to be successful components of landfill liner systems. So successful, in fact, that researchers and regulatory agencies are increasingly recommending FMLs for inclusion in closure cover systems. They argue, rightly, that the impermeability of FMLs makes them desirable candidates for closure covers (Koerner, 1992). What they fail to consider—or more likely don't consider in enough detail—is the issue of stability.

Landfill liners typically do not experience stability problems, because the normal forces exerted by the completed landfill offset sliding resistance along the sides of the landfill liner system. In contrast, closure covers, particularly those constructed on steep slopes and in areas of high seismicity, such as California, are inherently vulnerable to movement. Add the low frictional resistance of the materials used in the

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of available scientific literature indicates that the friction angles between FMLs and compacted clay range from 7 to 14 degrees (or 26 degrees for textured FMLs), and those between FMLs and geonets range from 7.3 to 10 degrees (not an issue for double-sided geotextiles thermally bonded to drainage net and placed on a textured FML). With these friction angles, none of the plots presented in Figure 2 for a high water table condition show a safety factor of 1.5 under static loading conditions. Conditions become even worse under seismic loading.

California's Department of Toxic Substances Control (DTSC) requirements pertaining to the closure and post-closure care of landfills state that the final cover shall be designed and constructed so that it can withstand a "maximum credible" earthquake. Slip failure along synthetic interfaces becomes almost inevitable under seismic loading for any slope steeper than 3 horizontal to 1 vertical. Let's examine one aspect of the seismic issue.

Different problem with an FML on a steep slope is related to a "liquefaction effect" of the interface. As a smooth or textured FML is placed on a clay layer compacted on a wet side of optimum, moisture will condensate at the interface. If placed and sealed at the edges, it will condensate moisture. This condensate moisture may become trouble during an earthquake. Because it is trapped in a confined space, when excited by earthquake motion, it may build pressure and create a temporary loss of friction between the FML and the soil. If air or water cannot escape at a sufficiently fast rate when the soil is reducing in volume due to vibrations, significant pressure may develop, with ensuing liquefaction effect, or air lubrication, at the interface. A result would be an instant and catastrophic failure, just as is the case with liquefaction in sand layers when loss of friction between sand grains is a result of the pore pressure increase. Apparently, a quantitative analysis of this type of liquefaction phenomenon has not been developed, but I urge consideration of the possibility of its occurrence at the interface and even within sand drainage layers, if present. Much more research is needed in this area.

Because of inherent difficulties in the performance of FMLs on steep slopes, one must think of ways to improve the design. If an FML must be used, one must look for ways to enhance its performance relative to overall system stability. Realizing that FML does not need to be a continuous single layer is probably the most important factor. Nailing pieces of an FML to the slope and overlapping them like roof tiles would not jeopardize infiltration potential and would greatly increase stability, decrease liquefaction potential as well as facilitate and simplify installation and repair. Of course, this method would not work when an FML functions as a landfill gas collector, as may be a case in many municipal waste landfills. Other methods, such as reinforced earth concept and geogrids, have been used to enhance the stability of landfill slopes, but neither of these approaches really solves the friction requirements between FMLs and contact materials. Short of physically connecting the FML to its foundation soils and to the soils on top of it, one must rely only on friction to provide long-term stability.

Long-Term Migration

Both federal and state regulations require that long-term migration of liquids through the cover and into underlying wastes be minimized. The State of California is somewhat more explicit in that its regulations cite a period of at least 100 years.

These regulatory requirements can often be met without a drainage layer or an FML, as shown by a detailed analysis of the expected runoff and infiltration rates on landfill slopes where the grade exceeds 10 percent (10H:1V).

The difference between flat and pitched roof decks offers and even clearer example of this analysis (Figure 1). Roof decks that are more-or-less flat are covered with materials like asphalt, coal-tar, or foam. These materials are virtually water-proof and must be installed as a single unit without leaky seams or cracks. This barrier is necessary because water has a tendency to collect and pond on flat roofs before it flows slowly to drainage outlets or evaporates. In contrast, water flows more swiftly down steep roof decks and never has the opportunity to collect in depressions. Such roofs are typically constructed of multiple units (like shingles or tiles) that are sometimes, but need not be, impermeable.

Any rainfall that contacts a landfill cover will either become runoff, evaporate from depressions on the surface, or infiltrate into the vegetated layer. Of the fraction that enters the soil, a portion will remain in storage in the soil pores or be lost to the atmosphere due to evaporation and transpiration; the rest will eventually migrate downward. If a cover system is to function properly, little, if any, of the water that falls on it should migrate beyond the compacted clay barrier layer and into the waste.

A Question of Slope

Cover System B has neither an FML nor a drainage layer. Two features of this cover system, namely the slope on which it is installed and the

1-meter-thick layer of compacted clay, combine to minimize the amount of water that is likely to come into contact with the wastes beneath it.

The steepness of the cover provides the initial barrier to infiltration by promoting greater runoff during rainfall events. Literature data (Water Resources Engineers, 1977) show that the increase in runoff on slopes of 10, 15, 20, 25, and 30 percent is 12, 20, 25, 28, and 30 percent, respectively, relative to slopes of 5 percent or less. Most of the vegetative soils in California have a runoff coefficient of 0.45 for conditions of the type that will prevail after closure of a site is complete. For Solano County, this coefficient is applicable to the mean (48 cm) and the 10-year annual (69 cm) rainfall event. For the 25-year (78 cm) and 100-year (90 cm) annual events, the coefficient increases to 0.5 and 0.56, respectively.

These coefficients indicate that the amount of water that would run off would be no less than 50 percent and as much as 74 percent, depending on the incline. The remaining water would either evaporate from the surface or infiltrate into the upper layer of the soil (vegetated soil cover). No measurable infiltration is expected to pass the vegetated cover layer on steeper slopes. Figure 3 summarizes the results of infiltration analysis using Thornthwaite's method (Thornthwaite, 1955). Conservatively, assuming the runoff coefficient of 0.17, only 1.3 cm of infiltration is expected to pass the vegetated soil cover.

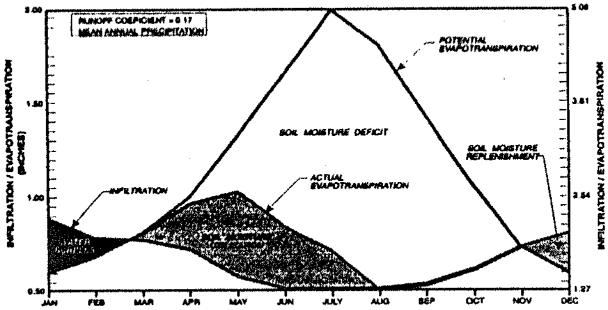

Figure 3: Landfill Cover Water Balance Analysis (Northern California)

Thornthwaite's method utilizes the concept of potential evaporation, which is defined as the amount of water that would be lost from the land surface by evaporation and transpiration if sufficient water were available to meet the demand at all times. In a recharge area such as California, these conditions are not realized, and actual evapotranspiration is always less than the potential evapotranspiration (Figure 3).

Clay Not Likely to Become Saturated

In the event that a small amount of rain does percolate through the vegetative cover and no drainage layer exists, the chances that the water will proceed into the foundation layer are minuscule. This is because the clay layer must become saturated before water will pass through it. Calculations based on the water balance method indicate that, in most years, no water would reach this layer. We can, therefore, expect unsaturated flow conditions to exist in this layer. In this case, hydraulic conductivity (*k*) is not constant; rather, it is a function of the water content, *w* with *k* decreasing as *w* decreases (Bear, et al., 1968). In general, hydraulic conductivities in an unsaturated state are much smaller (up to four orders of magnitude) than those in a saturated state.

The optimal water content of clay (*w*) at the time it is placed on top of the foundation layer is typically about 18 percent (California). At saturation, it typically has a water content of 27 percent. The void ratio (*e*) and porosity (*n*) of clay are 0.74 and 0.43, respectively. At $w = 18$ percent, the degree of saturation is 67 percent, leaving 14 percent of the volume available for water storage. Each unit volume of the 1-meter-thick layer of clay that would be installed as part of Cover System B would be able to store 13 additional centimeters of water. Calculations demonstrate that only 1.3 cm of water is expected to infiltrate into this layer every 10 years. Thus, even if the travel time of water through the clay layer is 3 years (for fully saturated conditions), it would still take 100 years for this layer to become saturated.

Not Worth the Risk

If, then, cover systems that consist only of clays and a vegetative soil layer provide sufficient impermeable barriers to percolation, it makes no sense to risk stability problems by including an FML in a closure cover when the slope of the cover exceeds 10 percent. Thanks to the low hydraulic conductivity of a clay layer and the unsaturated conditions that exist in it, the small amount of water that might pass into it will not travel to the foundation layer until the clay is saturated. And that may take more than 100 years under the conditions described in this article.

If designers insist on installing FMLs as part of landfill cover systems, infiltration potential and seismic stability analyses must be performed before proceeding with installation of the final cover.

Appendix

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