Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Optimization of a geocomposite drainage layer for closure of four hazardous waste landfills

R. J. DUNN, Kleinfelder, Pleasanton, California, USA
A. DE, Manhattan College, Riverdale, New York, USA
(formerly, GeoSyntec Consultants, Walnut Creek, California, USA)

ABSTRACT: Final closure of four hazardous waste landfills required the design of a multiple layer geosynthetic based cover. Key design constraints for the landfills and interstitial areas between them were steep slopes, a highly seismic environment, and the very large design storm for which the closure must be designed. Design flows within the geocomposite were required to not fully saturate the depth of the geocomposite. Design studies indicated that owing to different slopes and drainage path lengths, two types of geocomposite were appropriate to handle the flows. Because one geocomposite was considerably more expensive than the other, the layout of the different geocomposites was optimized to reduce costs. Consideration of construction operations was also incorporated to the layout optimization process.

1 INTRODUCTION

Final closure of four hazardous waste landfills at a closed hazardous waste disposal facility in Central California required the design of a multiple layer geosynthetic based cover meeting the requirements of the United States Environmental Protection Agency. The cover included a geosynthetic clay liner, HDPE geomembrane, geocomposite drainage layer and vegetative soil protective cover. A geonet was also installed within the soil layer to act as a barrier to animal burrowing. The drainage layer is mandated by regulation for this type of facility and is essential to enhance cover stability on the steep slopes.

The landfills at the site were constructed in canyons that had been enlarged to provide additional disposal area and daily cover material for waste disposal. Landfill construction predated later, more rigorous requirements for hazardous waste disposal promulgated in the 1980s. The landfills were all unlined, but the claystone bedrock that existed on the base and side-lopes of the landfills provided some limited containment. No leachate collection facilities were installed within or below the landfills. The landfills received bulk and containerized wastes during the period of 1979 to 1989, when closure activities at the facility were begun. Much of the waste was disposed in drums. After 1989, closure activities for on-site waste treatment ponds and pads, some of which had been located in the interstitial areas between the landfills (Figure 1), resulted in significant thickness of stabilized pond bottoms being placed above existing wastes to additional depths of 15 m or more. Total depths of waste materials and pond bottoms were as much as 50 m thick. Topographically the landfills formed sizable mounds extending well above the surrounding areas.

2 DESIGN CONSTRAINTS AND PARAMETERS

The major design criteria for the landfills cover systems are the ability to isolate waste material in the landfills from intrusion, to promote vegetative growth, limit infiltration of liquids into the wastes, and to be compatible with possible future capping of adjacent areas which might be required as part of further remediation activities at the facility. A seismic site exposure evaluation indicated that the Maximum Credible Earthquake (MCE) is a moment magnitude (M_w) event on a thrust fault, which underlies the facility property. This MCE is characterized with a mean peak horizontal ground acceleration (PHGA) of 0.86g and a significant duration of strong shaking of 10 seconds. Thus, the seismic impact is significant. Seismic loading generally was a very major constraint on the cover design, particularly with relation to slope stability of the landfills. Achieving appropriate slope stability without major waste and earthmoving efforts necessitated that the cover efficiently drain infiltration through the vegetative layer and thus keep seepage forces in the cover to a minimal level. Efficient drainage within the landfill covers also acted to control moisture content of the vegetative layer materials constructed from the on-site claystone materials that were processed to provide a soil material. This clayey silt soil was found to have a significant reduction in shear strength when saturated.

2.1 *Design Precipitation Event*

The design storm for the cover system was a Probable Maximum Precipitation (PMP) event with rainfall measuring 340 mm over a 24-hr period. The PMP was developed by statistical evaluation of 47 years of historic rainfall data. This is an event with a return period exceeding 10,000 years. Regulators imposed the requirement that in addition to handling this large storm with suitable surface water drainage facilities, the landfill cover drainage layers must also handle storm flows without saturating and potentially leading to partial or full saturation of the overlying 0.6 m thick vegetative layer. From the outset of the project a geocomposite drainage layer was favored over one composed of gravel materials both for reasons of cost and better slope cover stability, particularly during earthquake loading.

2.2 *Conceptual Drainage Layer Design*

Grades in the landfills were generally around 4 horizontal to 1 vertical (4H:1V). The crest areas were designed to be graded to an average slope of 4%, with a maximum slope length at this flat grade of 15 m. Slope stability of the landfill cover system required that horizontal benches be constructed on the landfills at vertical intervals not exceeding approximately 9 m. These benches also provide access for future maintenance activities and allow for a surface water drainage system that can handle the PMP without large-scale ditches or pipes on the landfills.

The interstitial areas between the landfills had been used for waste treatment operations. While waste materials had been removed from these areas, their final clean closure had not been accepted and approved by the regulatory agencies. Additionally, site hydrogeologic evaluations indicated that these areas were contributing infiltration to movement of subsurface contaminants away from the landfill area in the underlying groundwater. In order to complete closure of these areas and also reduce the infiltration potential, it was decided to cap the interstitial areas with covers like that planned to be constructed over the landfills. Within the interstitial areas there was not a similar requirement for benches as topography typically was not as steep as the landfills. Because the interstitial areas were primarily composed of cuts in the underlying claystone, effects of earthquake shaking were much less than on the landfills and benches were not needed for stability reasons. Much of the interstitial areas were at flat grades of 10% to 20%.

The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder 1994a & b) was used to develop a conceptual design of the geocomposite drainage layer. The geocomposite covered the entire area to be capped. However, these studies quickly indicated that the very large size of the PMP design storm necessitated that the drainage layer must discharge at each bench within the landfills. Thus, each segment of geocomposite drainage layer only collects infiltration that occurred through a tributary area between two adjacent benches. The maximum flow length within a segment of the drainage layer was thus limited to no more than 45 m on the landfills. This concept was consistent with the design team's general practice to design for discharge of flow at each bench to eliminate the concentration of collected infiltration for the entire landfill at the toe where stability becomes very critical. Within the interstitial areas the conceptual design was to discharge the drainage layer to the central main drainage channels that were to be located down the base of each interstitial area. This resulted in some longer flow paths in this area of up to 62 m. With the design concept established, more detailed design was carried out to produce construction level plans and specifications.

3 DESIGN ANALYSES

The HELP model was again utilized during detailed design to evaluate both the infiltration through the proposed cap to show compliance with regulations for hazardous waste landfill closure. Additionally, the HELP analyses also provide data applicable to evaluation of the hydraulic performance of the geocomposite drainage layer. These analyses allowed for the selection of suitable geocomposite materials to meet the design requirement to keep the drainage layer from reaching saturation during the PMP design storm. The hydraulic analyses and geocomposite selection process are described in the following sections.

3.1 *HELP Model Background*

The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder, 1994a & b) was developed by the U.S. Army Corps of Engineers Waterway Experimentation Station for the U.S. Environmental Protection Agency (USEPA) to simulate the effects of the hydrologic process on landfills. The HELP model is a quasi-two-dimensional, deterministic water-budget model that simulates the hydrologic process. Simulation periods may vary from 2 to 100 years based on the extent of climatological data available or generated. The results may be reported in daily, monthly, annual, and long-term average water budgets. The first hydrologic process considered by the program is precipitation, which includes both rainfall and snowmelt. The program then calculates daily infiltration into the landfill by summing the daily rainfall and snowmelt and subtracting the surface runoff and surface evaporation. Infiltration is either removed by evapotranspiration, percolation through the landfill, or is removed by lateral drainage.

3.2 *Method of Analysis*

Three general types of input parameters are required as follow: weather data, soil data, and design data. The weather data can be categorized by precipitation, temperature, solar radiation, and evapotranspiration. Program-supplied or user-supplied data input options exist for all these categories. The soil data is categorized by four types of layers - vertical percolation, lateral drainage, flexible membrane liners (FMLs), or barrier soils. The user can either select a list of common soil textures from the HELP database or supply layer texture data. The soil texture data includes porosity, field capacity, wilting point, and saturated hydraulic conductivity. The design data are classified as layer design or general site data, which may include parameters on drainage length, drain slope, leachate recirculation, and subsurface in-flow. Additional design data include the United States Soil Conservation Service (SCS) runoff curve number, surface conditions, area, and the percentage of area where runoff is possible.

As with most models, the HELP model incorporates several assumptions and has some limitations. The model uses quasi-two-dimensional flow (flow can only occur vertically or horizontally) to quantify the movement of water through the layers. The model uses Darcy's law that assumes that all materials are fully saturated, which very likely is not the case in a landfill cover. Experience has indicated that the results produced by the model are in reasonable agreement with the performance of landfills located in humid climates. However, in arid and semiarid regions, HELP has overestimated infiltration rates (Sharma & Lewis, 1994). Therefore, the model probably provides conservative estimates of infiltration rates as the landfills area is moderately arid.

The HELP model also generates water balance results. With all the input parameters and data, the model produces average annual and peak daily values. Units of output are in inches, cubic feet, and percentage of total precipitation. The model will generate these results for collection through lateral drainage layers, percolation through barrier layers, and maximum head and its location on geomembranes. This enables the engineer to design the drainage layer and to satisfy regulatory requirements for the design of a cap system.

3.3 *Final design Input Parameters*

The HELP model performs the water balance using input on climatologic data, material layer and vegetative cover characteristics, and design data including information on installation quality. Maintained in the model's database are default climatologic data for various cities throughout the United States, default options for vegetative types, and default properties of soil types for use when site and material-specific data are unavailable. The parameters selected for the model are discussed below.

3.3.1 *Climate*

Synthetic precipitation data for a 30-year period was generated using data from within the HELP database library for a similar coastal station in California, and normalizing the rainfall to the location of the landfills. The data used by the HELP model was checked against the National Oceanic Atmospheric Administration data (NOAA, 1992) to verify the suitability of the synthetic percipitation data.

The average annual precipitation for the site is 315 mm. The normal mean annual temperature is 57.3°F (14.0°C). Default evapotranspiration and solar radiation data was used for a latitude of North 35°00'.

Three precipitation cases were considered. The first case was the median annual rainfall that was transformed to synthetically generate 30 years of rainfall that was representative of the landfills site. The second case represents the effect of irrigating the cap during the first two years after construction to aid with establishment of vegetation. This case modifies the synthetic rainfall by specifying 4 mm of precipitation every other day from 1 May to 31 October to model irrigation on the cap 3.5 times per week during the dry summer months. The third case represents the design storm rainfall having a probable maximum precipitation (PMP) of 340 mm. The PMP storm was modeled following a day of 75 mm of precipitation to simulate nearly saturated soil conditions. Runoff coefficients consistent with those for surface water drainage design were applied in the HELP analyses. This day with 75 mm of precipitation corresponds to the first peak rainfall generated for the 30 years of synthetic rainfall data. The analysis using the PMP yields the highest amount of water collected in the geocomposite drainage layer in most cases for the flatter slopes on the cap. The analysis considering an irrigation cycle on the cap yields the higher amounts of water collected in the geocomposite for steeper slopes. Specifications for the geocomposite drainage layer are developed based on the rainfall scenario for which the greatest head is calculated, which can be either the PMP or the irrigation cycle depending upon the slope, and that the maximum flow is fully carried within the plane of the geocomposites. No modifications were made to the evapotranspiration, solar radiation, or temperature input data files, which were taken from default HELP database files.

3.3.2 *Model Cap Section*

The cover system was modeled from top to bottom as a vertical percolation layer 0.6 m thick and with a moderately low hydraulic conductivity of 1 x 10^{-6} m/s, the geocomposite lateral drainage layer discussed in more detail in the next section, an 1.5 mm thick HDPE geomembrane layer , and an underlying geotextile backed geosynthetic clay liner 5 mm thick.

3.3.3 *Lateral Drainage Layer Characteristics Modeled*

The lateral drainage layer was modeled as a 5 mm thick geocomposite. Two types of geocomposite differing in their transmissivity and thus, hydraulic conductivity were evaluated. The high transmissivity material had a transmissivity of 5 x 10^{-4} m^2/s (hydraulic conductivity of 0.1 m/s), while the lower transmissivity geocomposite had a transmissivity of 1 x 10^{-4} m^2/s (hydraulic conductivity of 0.02 m/s). Generally, the two materials differ in that the high transmissivity material is a tri-planar geonet product while the lower transmissivity product was a bi-planar product. In each case, the geocomposite consisted of a polyethylene core, with nonwoven polypropylene geotextiles on both surfaces. The geotextiles on the upper and lower surfaces of the geocomposite were specified to have minimum mass per unit area values of 270 and 240 g/m^2, respectively. The apparent opening size (AOS) specified for the geotextile was 0.21 mm. These materials were selected based upon experience on other landfills and review of manufacturers specifications information.

3.3.4 *Slopes and Drainage Lengths*

A range of combinations of slope inclinations and drainage lengths were modeled in order to evaluate the type of geocomposite required over the entire site. The combinations are listed in Table 1. These combinations represented zones into which the landfills and interstitial areas could be divided. Thus once the required geocomposite was determined it could be assigned to a zone and a layout map of the two types quickly developed for use in the project.

3.4 *Final Design Analyses Results*

HELP model output provides a variety of calculated parameters. Both average values and peak daily values are provided. For selection of the appropriate geocomposite types, the decision on geocomposite types in a particular zone was based upon the input parameter of head build-up on the geomembrane liner. Calculated values of this head value were evaluated for the slope and drainage length combinations as presented in Table 1. Peak daily values of head in excess of the geonet thickness of 5 mm did not meet the criteria of an unsaturated geocomposite and thus indicated that a specific combination of slope and drainage length, coupled with the assumed geocomposite type, was not suitable for the zones represented by the combination.

Table 1. Slopes and Drainage Lengths Evaluated

Slope	**Drainage Length (m)**
Landfills Areas	
4 %	15
10 %	25
25 %	45
30 %	34
Interstitial Areas	
10 %	43
20 %	61
35 %	21

All three precipitation cases were evaluated for each of the slope and drainage length combinations to ensure that the selected geocomposite type accommodated the worst-case event. The controlling precipitation event varied depending upon the slope. In the landfill areas the governing precipitation criterion was the PMP for slopes equal to or flatter than 25%, whereas it shifted to the irrigation criterion for steeper slopes. In the interstitial areas the PMP case was governing for slopes equal to or flatter than 20%, with the irrigation case governing for the steeper slopes. This is attributed to variation in slope length.

The selection of geocomposite is based on the maximum head calculated for the worst configuration for that particular geocomposite type. The high transmissivity drainage geocomposite having a hydraulic conductivity of 0.1 m/s is required for slopes flatter than 25 % (4H:1V) in the landfill areas. The maximum calculated head on the liner for the PMP rainfall scenario analyzed for the flattest area (worst configuration) with a 4% slope is 1 mm. Since the maximum calculated head does not exceed the 5 mm thickness of the geocomposite, the selection of the high transmissivity material is appropriate. Slopes equal to or steeper than 25 % (4H:1V) may be constructed with the 5 mm thick lower transmissivity geocomposite having a hydraulic conductivity of 0.02 m/s. The maximum calculated head on the liner for the PMP rainfall scenario analyzed for the flattest slope area (worst configuration) with a 25% slope is 2.6 mm.

Similarly, slopes equal to or flatter than 20 % (5H:1V) in the interstitial area require the 5 mm thick high transmissivity geocomposite having a hydraulic conductivity of 0.1 m/s. The maximum calculated head on the liner for the PMP rainfall scenario analyzed for the flattest area (worst configuration) with a 10% slope is 1 mm. Since the maximum calculated head does not exceed the 5 mm thickness of the geocomposite, the selection of the high transmissivity material is appropriate. Slopes steeper than 20% (5H:1V) may be constructed with the lower transmissivity geocomposite having a hydraulic conductivity of 0.02 m/s. The maximum calculated head on the liner for the irrigation rainfall scenario analyzed for the worst configuration is for a 20% slope is 1 mm.

3.5 *Specification of Transmissivity*

The HELP model analyses were run with the assumption of an idealized geocomposite drainage layer with no clogging. In reality, several factors can result in clogging of a geocomposite and thus reduce drainage capacity. Koerner (1994) lists potential clogging phenomena including: 1) intrusion of the adjacent geotextiles into the geonet core space, 2) creep deformation of the geonet and or/ adjacent geotextiles into the geonet core space, 3) chemical clogging of the geonet, and 4) biological clogging of the geonet. Koerner also suggests appropriate factor of safety ranges for both liner and cover applications of geocomposites. For covers where stresses are low, the factors of safety are within a range of 1.0 to 1.5 depending upon the parameter. The largest factor of safety value of each was selected which when multiplied together indicated a correction factor of 3.78. The factor was rounded off to 4 and was applied to the results from the HELP model analyses. Thus, the transmissivity values were increased by a factor of four to account for clogging. The specified values thus were 2×10^{-3} m^2/s for the high transmissivity geocomposite to be used on the landfill top crests and portions of the interstitial areas and 4×10^{-4} m^2/s for the lower transmissivity material to be used on other slope areas. The layout adopted for construction is shown in Figure 1 for two complete landfills and the interstitial areas.

4 CONSTRUCTION CONSIDERATIONS AND FINAL LAYOUT

In order to reduce construction costs it was desired to minimize the area of the higher transmissivity product, which was significantly higher in cost. The initial layout based upon HELP model results was optimized by consideration of two criteria. First, any areas where a higher transmissivity segment could connect to a lower transmissivity portion, mainly in the interstitial areas, supplemental HELP analyses were completed as needed to model the specific slope and drainage length to determine the maximum depth of flow within the geocomposite at the connection point. This value was then checked against the hydraulic capacity of the down-slope lower transmissivity segment over the specific slope and drainage length. If the lower geocomposite could not carry the total flow, it was modified to the higher transmissivity material. The second criterion was consideration of construction operations to eliminate small areas where change from the higher to lower transmissivity materials simply was not warranted as the cost savings in material would likely be offset by extra installation costs. These layouts were verified by review by a geosynthetics installer.

5 SUMMARY AND CONCLUSIONS

Selection of a suitable geocomposite drainage layer for the covers of four hazardous waste landfills and the interstitial areas between them required the use of high capacity geocomposites to handle the very large infiltration flows generated by the design PMP storm. Additionally, high capacity geocomposites provided the added benefit of enhancing moisture reduction on the vegetation layer soils at the top of the covers, which enhanced slope stability. The HELP model was used to evaluate the required minimum transmissivity required for the geocomposite to successfully transmit design flows without saturating. These analyses indicated that a sufficiently high transmissivity was required in at least certain flatter areas of the cover such that a tri-planar geocomposite was required. Given the significantly higher cost of the tri-planar material, it was deemed appropriate to detail the geocomposite layout so that less expensive bi-planar materials could be utilized as well. The HELP model again proved to be a powerful tool to determine which areas required a high transmissivity geocomposite and those areas where a lower transmissivity material also met design requirements. The theoretical transmissivity values that are indicated by HELP analyses were then adjusted to account for several factors that can result in clogging of the geonet and reduction in flow efficiency. Finally, the layout was optimized by consideration of constructability issues, including the additional cost of installation of small areas of different geocomposites. The result was an optimized, cost effective design that meets all design criteria.

REFERENCES

Koerner, R. M., 1994, *Designing with Geosynthetics*, 3rd Edition, Prentice Hall, Englewood Cliffs, New Jersey.

National Oceanic and Atmospheric Administration (NOAA), *“Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1961-1990, California”*, January 1992.

Schroeder, P.R., Aziz, N.M., Lloyd, C.M., and Zappi, P.A., "The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3", EPA/600/R-94/168a, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C., 1994a.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., and Peyton, R.L., "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3", EPA/600/R-94/168b, U.S. Environmental Protection Agency, Office of Research and Development, Washington D.C., 1994b.

Sharma, H.D. and S.P. Lewis, "*Waste Containment Systems, Waste Stabilization, and Landfills*", John Wiley and Sons, 1994.

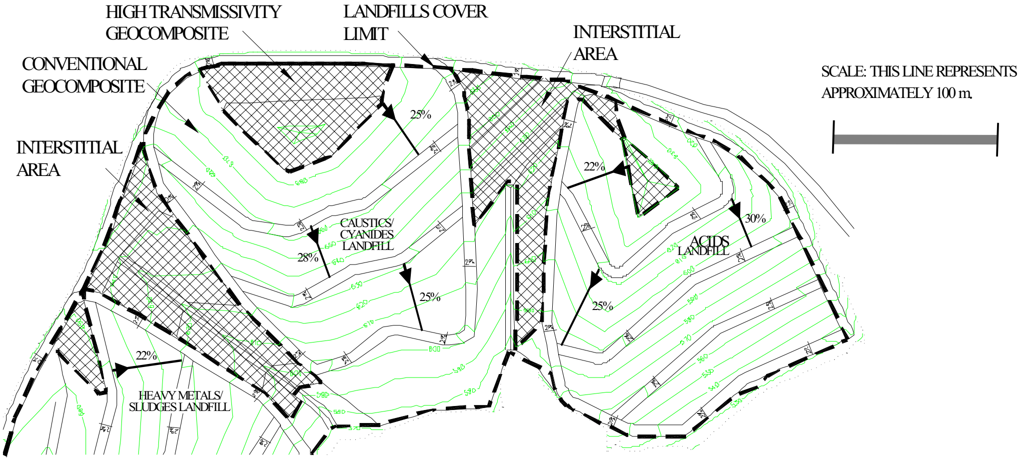

Figure 1. Adopted configuration of two geocomposite types on two landfills and interstitial areas.