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Performance of Compacted Clay Liners in Northern Iraq

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ABSTRACT

The present study aims to evaluate the behavior of a landfill structurally and hydrologic ally. The landfill is presumed to be constructed in Zakho-Iraq. The effect of changing the angle of side slope is studied using PLAXIS2D. The results indicated that when changing the side slope from 29.74° to 14°, the safety factors have increased. Further, the effect of changing the thickness of the clay liner has also been studied. It was found that the liner thickness has little impact on the safety factor, so that it can be neglected. Hydrological study of compacted clay liner was undertaken for three years using VADOSE/W2007 under the influence of the same slope that was previously introduced in the stability investigation and found that the amount of runoff increases with increasing the side slope angle, while the amount of leakage is changed subtly. Lateral side slope for the liner was selected to be 26.56 ° which gave a safety factor of greater than 1.5 and an acceptable leakage of water. The stability was also evaluated for the geomembrane under the same mentioned side slopes and found that the safety factor has increased. Three types of liners were studied: compacted clay liner, geomembrane and combined liner have been investigated under eight years of simulation using Vadose/W. The study showed that the minimal amount of leakage was achieved when using combined liner, compacted clay liner then the geomembrane respectively. The impact of number if punctures (drains) was also investigated. It was found that when increasing the number of puncturesin the combined liner and the geomembrane led to an increased leakage. A major conclusion was a landfill could be constructed without a bottom liner system or leaching collection and removal system if a combined liner is used assuming to have good quality assurance.

Keywords: Geosynthetic , compacted clay linear , geomembranr linear , plaxis2d , VADOSE/W , Combined linear.

INTRODUCTION

The average amount of waste generating from housing units is increasing as a result of rising population and factory activities also due to the repeated wars that left huge amounts of Waste. Therefore an urgent necessity appeared to protect the environment from the negative impact of waste by putting them in form of landfills which isolate them properly from environmental impact and reduce the risk to the environment. Omeri and Boddula (Omeri and Boddula, 2012) conducted a theoretical study by using Plaxis2D and SLOPE/w2007. They found when reducing the side slope of the landfill the safety factor increased. They also found that Plaxis program gave a factor of safety of about 15-30 % more than the results obtained from the SLOPE/w program. In addition the factor of safety remains constant or decreases for an increase or decrease in the unit weight of the materials when using the program SLOPE/W.

The impact of adding geogrids to compacted clay liners was investigated using the program PLAXIS 2D, (Mohammed, 2014). It was found that the safety factor increased by 25%.

The impact of adding different types of vegetation cover (trees and grass, bushes and grass, grasses alone) over a landfill was investigated with change the thickness of the lining, they found that the adding of vegetation reduces the amount of water leaked into the landfill during the rainy season, noted that the process of transpiration give the highest value in the case of trees and grass for this reason be the amount of water leaked into the liner gives less value if there are trees and grass(Abichou, 2003).

Three different types of the liners with the leakage rate were investigated using field results found that the composite liner gives a water leak rate less than others followed by Geomembrane with compacted clay liner and then geomembrane liner only (Repert, 2004). A variety of studies have shown that the amount of water leaked through the composite liner gave less valuable then compacted clay liner and geomembrane liner (Rowe, 2012).

The impact of increasing the diameter of drain within the geomembrane liner was investigated, The study shown that increasing of diameter of drain with in the geomembrane liner increases its overflow leakage from Q = (250-500) m3/s when diameter was 0.5 mm to Q = (32-63000) m3/s when diameter became 5.6 mm (Rowe, 2012).
A variety of studies have investigated the effect of changing the thickness of the layer liner, One of it for three different liners with three different thicknesses by the program Unsat-H and founded when changing the thickness of the layers lining doesn't effect on the amount of water leaked into the landfill (Abichou, 2003).

2-MATERIALS AND METHODS:

Model of PLAXIS 2DGeological Composition and Structural Elements of the model used in the analysis of slope stability of liner by using PLAXIS2D program. A plane strain model was assigned by taking half of landfills section, figure (1). Materials models and parameters are given in table (1). The geomembrane was modelled as a geogrid model which follow a linear-elastic behavior also modelled as being impervious, table (2). The interfaces between the geomembrane and the surrounding layers was considered.

Table (1): Parameters for the Mohr-Coulomb model of compacted clay liner and geomembrane liner by program Plaxis2D

Material	Model	Case	Dry density ,kN/m3	Saturated density ,kN/m3	Young's modulus, MPa	Poisson's Ratio	c', kPa	Ø', o	References
Local soil	Mohr- coulomb	Drained	17	17	150	0.3	5	23	[5]
Filter			19	19	39	0.2	1	40	[14]
Clay liner			16	18	20	0.4	24	29.2	[8]
Level layer			16	18	20	0.4	24	29.2	[8]
Waste layer			11	15.4	2.5	0.45	30	20	[8]
Deep silt			19	19	40	0.2	1	33	[2]
Geomembrane	Linear-elastic	Non-porous	Can be simulated as Geogrids						[10]

Table(2):Parameters for Structural Elements of Geomembrane liner by program PLAXIS2D

Material name	Geogrids
EA	200 kN/m
Interface R_{inter}	0.8

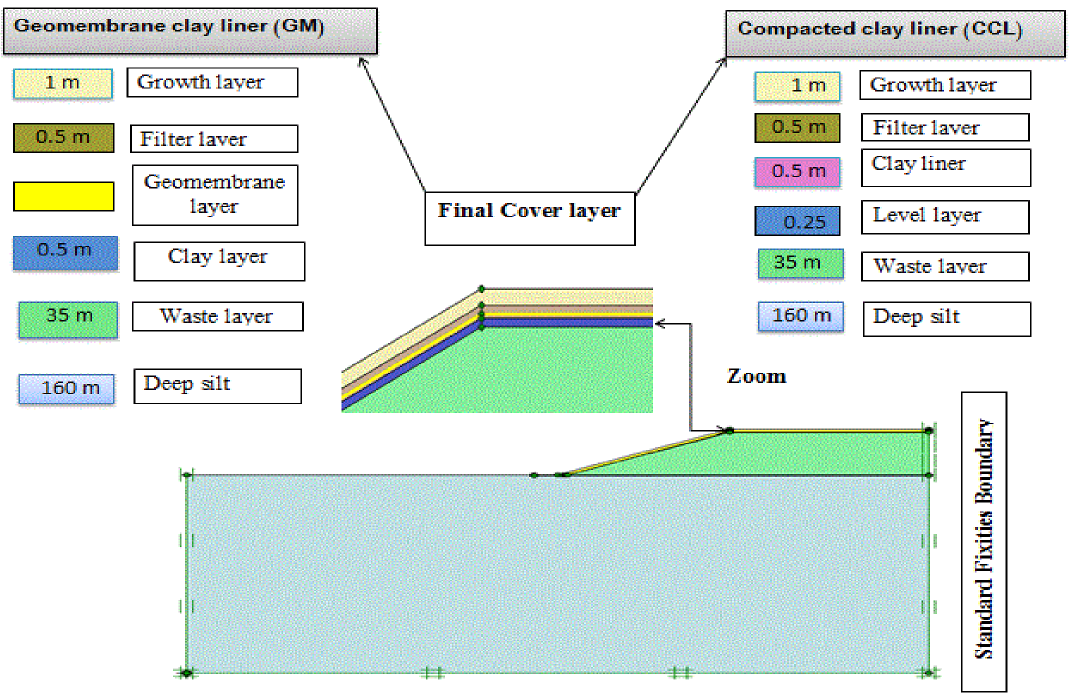

Figure (1):Model of CCL and GM in program PLAXIS2D

Model of VADOSE/W

The hydrological performance of the landfill was evaluated using the finite element program VADOSE/W. It allows analysis of the flow through unsaturated zones due to surface transient boundary conditions, i.e. fluxes depending on atmospheric and surface conditions (e.g. Vegetation - root transpiration, surface evaporation and weather conditions, temperature, humidity, wind speed and precipitation), [7] Modelling parameter used in the analysis are tabulated in table (3) and (4). The properties of the materials used in the analysis require the soil water characteristics curves, figure (2). They were derived from a build-in function in VASODE/W.

The model was constructed using surface layer option. Soil properties were listed in table 5. The bottom edge of the model had a unit gradient as boundary condition. Further, the initial temperature for the materials was set to 7.75° C which resembles mean air temperature of January where the simulations started with. Weather data set from 2003 – 2010 was used in the simulations.

The impact of construction quality of the geomembrane was also investigated. The geomembrane was presumed to have good to medium quality construction which represent one and two punctures respectively [11]. A puncture of 10 mm diameter was modelled as a seepage face. The impact of vegetation was also introduced in the analysis. Vegetation properties are shown in table (5).

Table (3): Modeling parameter of finite element program VADOSE/W for all liner

Material	Mass specific heat capacity, kJ/kg.C		Soil mineral thermal conductivity, kJ/day.m.C		Coefficient of compressibility,1/ kPa	$K_{saturated}$, m/day	References
	Frozen	Unfrozen	Frozen	Unfrozen			
Local soil	121	125	1755	2231	$1*10^{-5}$	0.00634	[4]
Filter	65	99	1304	1405	$1*10^{-5}$	0.0864	[14]
Clay liner	147	156	1889	2348	$1*10^{-5}$	8.64e-005	[4]
Level layer	147	156	1889	2348	$1*10^{-5}$	8.64e-005	[4]
Waste	125	150	2300	2500	$1*10^{-5}$	0.864	[3]
Geomembrane	Can be simulated as a line						[5]
Geosynthetic	104	108	2032	1625	$1*10^{-5}$	8.64e-007	[5]

Table (4): Soil water characteristic curve for applying in VADOSE/W models for Geosynthetic layer

Material	Soil-water characteristic curve	Soil-water characteristic curve Parameters		
		a, kPa	m, kPa	n, kPa
Geosynthetics	Based on Fredland-Xing function	3.03	0.667	3

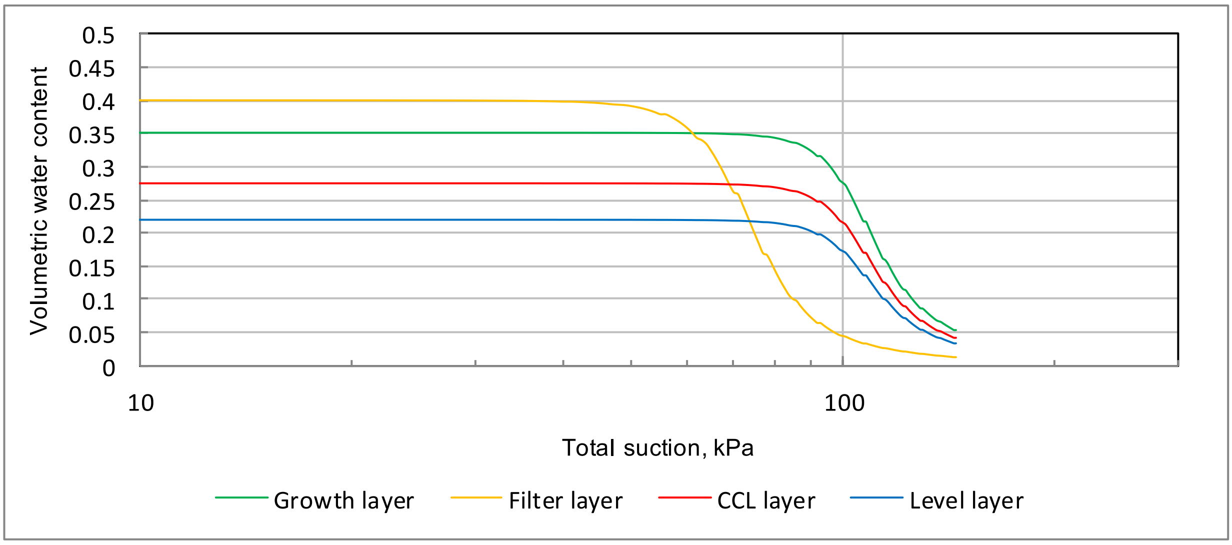

Figure (2): Soil-water characteristic curves of the top liner system materials used for VASDOE/W simulations.

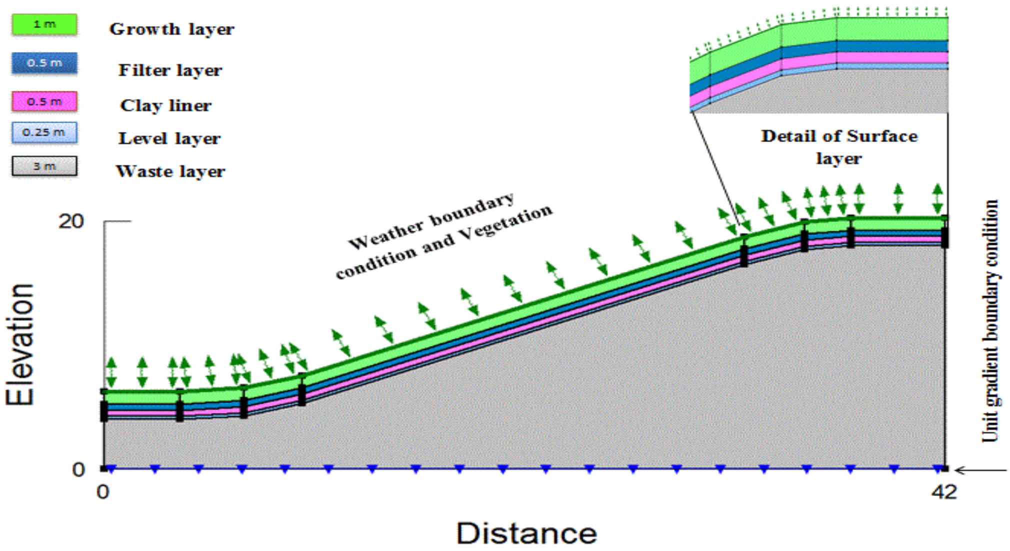

Figure (3): CCL with side slope 26.56° and layers and Boundary condition

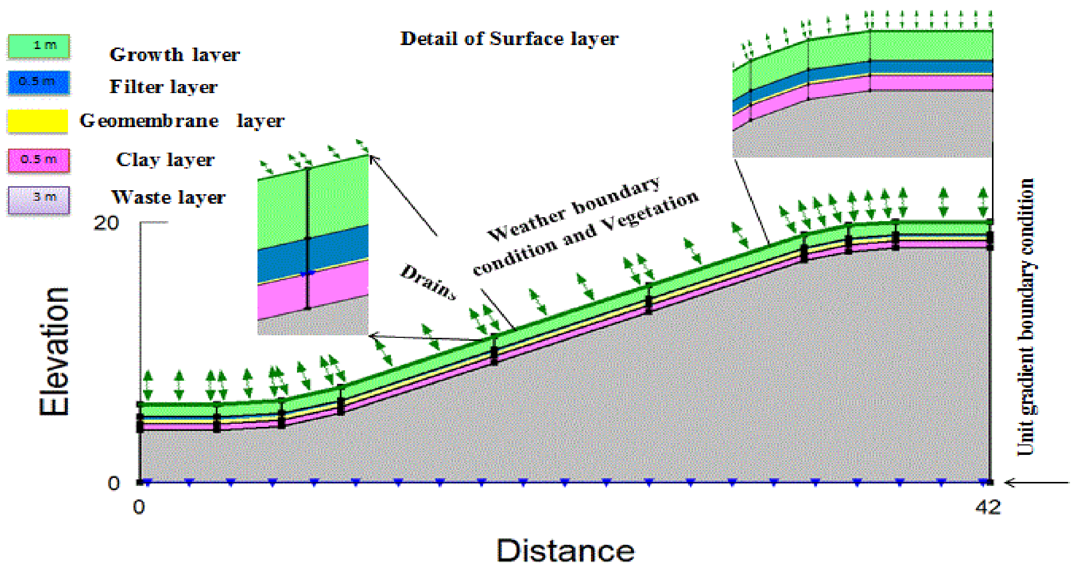

Figure (4): GM with side slope 26.56° and layers and Boundary condition

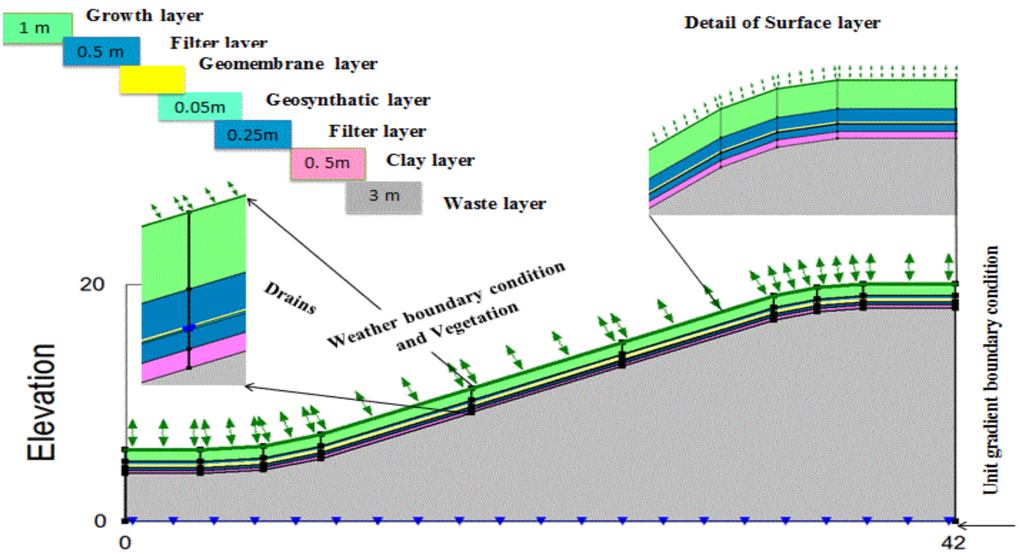

Figure (5): CL with side slope 26.56° and layers and Boundary condition.

Table (5): Vegetation properties applied in VADOSE/W models for all liner

Root depth VS Days		Leaf area index vs Day		References
Days	**Root depth (m)**			
7	- 0.1	**First day**	74	[3]
22.7	- 0.14704	**Last day**	274	
48.736	- 0.26638	**Quality**	Good	
78.669	- 0.37358	**Number of years**	8	
116.61	- 0.3925	**Number point per year**	30	

3 DISCUSSIONS

Preliminary Investigation

The stability analysis was evaluated for different side slope of the landfill (14 °, 18.43 °, 21.8 °, 24.56 °, 29.74°) using PLAXIS2D. The safety factor was also determined under different thickness, namely (0.4, 0.5, 0.7) m. The second step was to evaluate the hydrological performance at different sloping angles using VADOSE/W. Three years of weather data was used for these preliminary simulations. The amount of runoff, cumulative leakage through liners were taken as a bases for comparison.

As a general rule, a safety factor of 1.5 was considered as criteria for factor of safety selection. On the other hand, the minimal amount of leakage was taken as a selection guide amount the investigated layouts.

Stability investigation by PLAXIS 2D

Figure (3) shows the impact of side slope and liner thickness on the safety factor. It can be noted that the factor of safety for CCL was increased by 50% when reducing the side slope from 29.7 ° to 14 °. The angle 26.5 °yielded a safety factor of about 1.5 which makes it the preferred side slope angle in this study.

Further, when introducing the geomembrane in the upper liner system, the safety factor increased by 6%. On the hand, the impact of CCL thickness had very little effect of the safety factor, figure (6), accordingly, the thickness was set to 0.5 m in the detailed analysis as it will be discussed later. The failure envelope had a circular slide surface in case of CCL while a sliding failure surface was encountered in geomembrane.

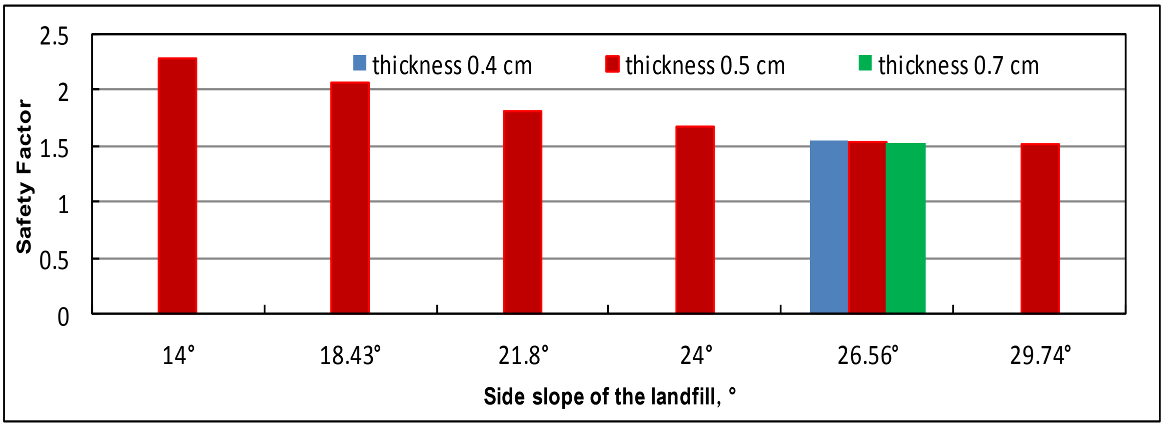

Figure (6): Safety factors under different side slopes and CCL thicknesses.

Hydrological investigation by program VADOSE/W

Logically, the amount of runoff was increased by about 1.6 times when the side slope increased from 14° to 29.74°. The amount of cumulative leak through the CCL into the waste mass decreased by 9% when changing the angle from 29.74° to 14°. It should be noted that the negative sign of the leak values in figure (7) indicates a downward movement of water, i.e. leakage

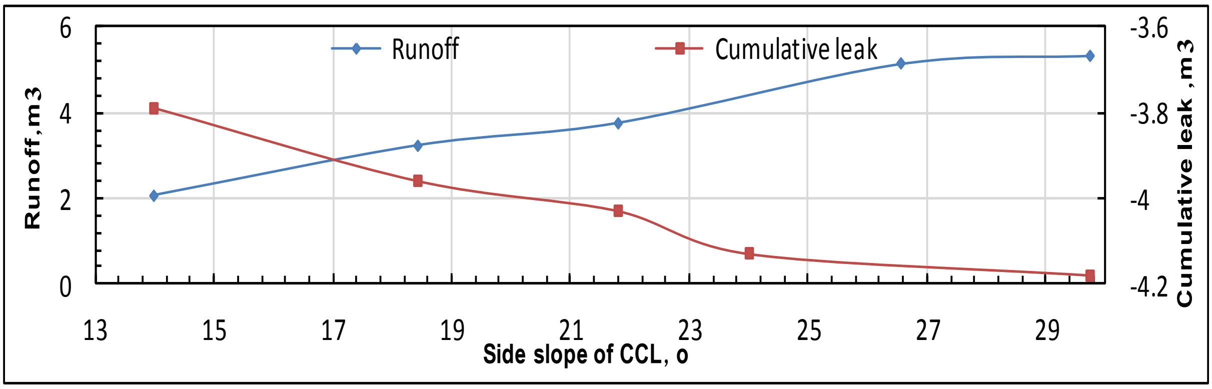

Figure (7): Runoff at different values of the side slope of the landfill. Cumulative leak at different values of the side slope of the landfill.

Concluding remarks

Based on the previous discussion, the side slope angle was selected to be 26.56° that yielded a safety factor of about 1.5. Also this angle gave a reasonable leakage value after which value stabilization encountered.

In the next article, a detailed hydrological analyses were conducted by taking into account eight years of weather data. Other variables were also introduced like the impact of vegetation, construction quality (number of punctures) and different layouts of lining systems (geomembrane and combined liner).

Detailed hydrological investigations using VADOSE/W

The following discussions were divided into two parts, 1) analyses without vegetation cover, 2) analyses with vegetation cover. Water balance relations, saturation ratio of liner and leakage were taken as comparison objects.

Analyses without vegetation
Water balance relations

Figure (8) shows water balance relations for three liner systems, namely CCL, GM and CL. It can be noticed that after six months of service the storage reached its ultimate capacity. The evaporation values were continuously increasing with time which reflect the effectiveness of constructing landfills in arid areas, figure (8). Liners temperature was almost as high as mean air temperature which can effectively contributes in the extraction of percolated water out of the landfill body.

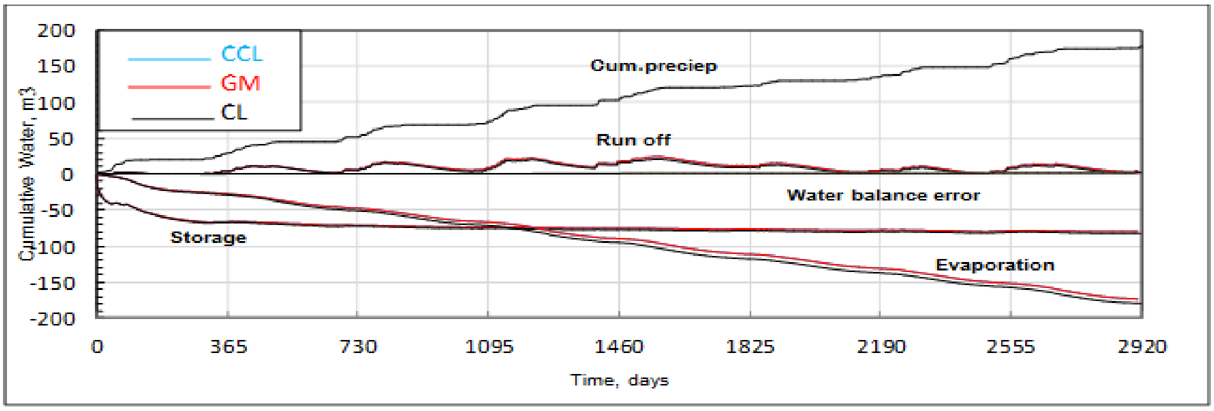

Figure (8): Water balance relation for: CCL, GM with one drain and CL with one drain in case no vegetation.

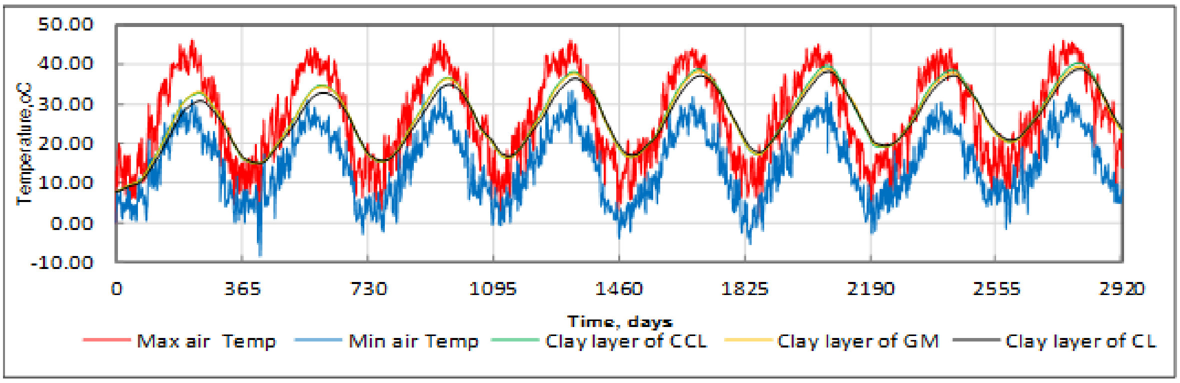

Figure (9): Time versus Temperature of the clay layer for CCL, GM with one drain and CL with one drain in case no vegetation

Saturation ratio

Figure (10) shows the saturation ratio along eight years of simulation for clay liner element in the lining systems CCL, GM and CL. The starting point (i.e. about 80%) corresponds to the optimum moisture content assuming the materials to be compacted at the maximum dry density. The saturation ratio for the CCL and CL systems were continuously decreasing reaching 10% saturation which is practically dry. On the other hand, the clay liner element in the GM liner system was continuously increasing and stabilizing to 100%. This could be attributed to the data collection from the node that is adjacent to the puncture. Another point was selected far from the puncture and showed a similar behavior as for the CCL and CL.

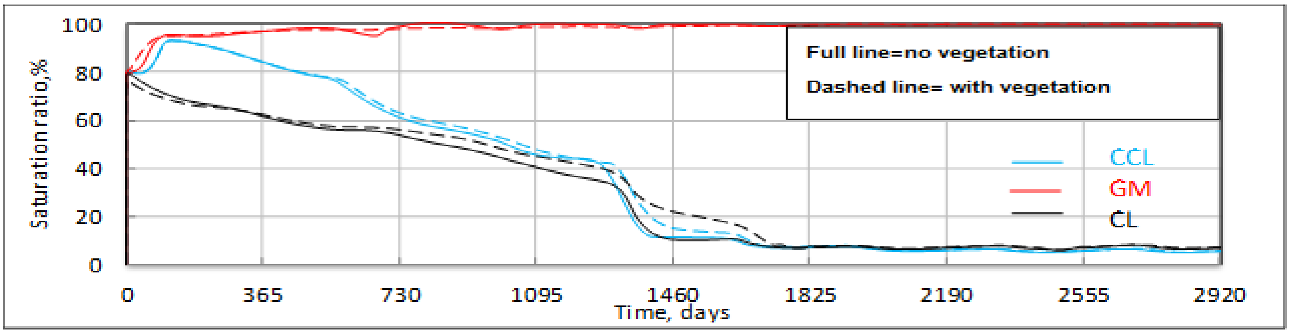

Figure (10): Time versus Saturation ratio of the clay layer for CCL, GM with one drain and CL with one drain in case no vegetation and with vegetation.

Cumulative leak

The highest leakage was obtained for the GM lining system because it had medium quality of construction, i.e. one puncture. The CL yielded the lowest leak values table (6), because it comprised of a compacted clay liner plus a geosynthetic clay liner and geomembrane liner, figure (11).

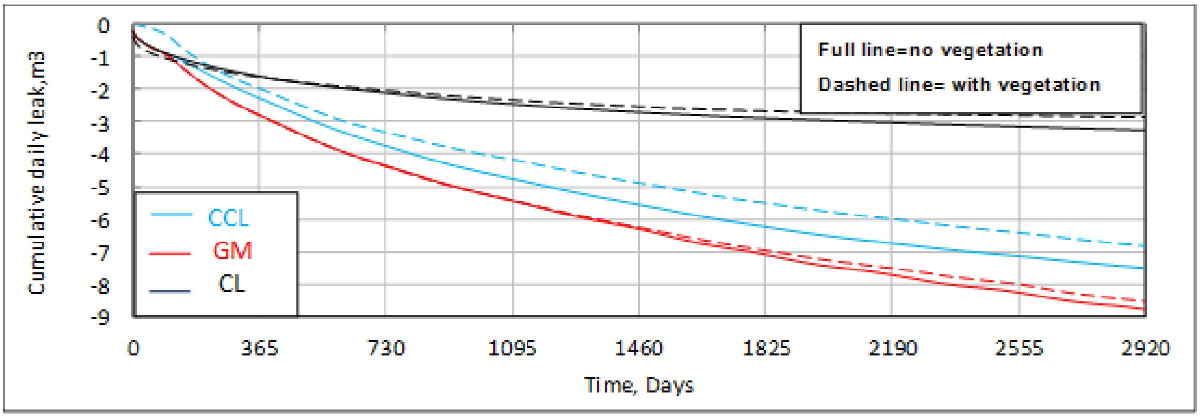

Figure (11): Time versus cumulative daily leak for CCL, GM with one drain and CL with one drain in case no vegetation and with vegetation.

Analyses with vegetation

The model used in section 4.2.1 was modified so that the vegetation effect was taken.

Water balance relations

The results in figure (12) showed a similar behavior for the water balance relation except the difference in the evaporation. The evaporation rate was increased by about 37% when comparing it with the absence of the vegetation. This means that the existence of vegetation cover will help the extraction water out of the landfill body, by other words, lower leakage values. The leakage values were reduced by the shown values in table (6) for CL, GM and CCL when taking the no vegetation case as a reference.

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Table (6): Percentage reduction in leakage values taking the no vegetation case as a reference.

Line system	Leakage, no vegetation, m^3	Leakage, with vegetation, m^3	Percentage reduction, %
CL	-3.26	-2.85	13%
GM	-8.78	-8.5	3%
CCL	-7.51	-6.83	9%

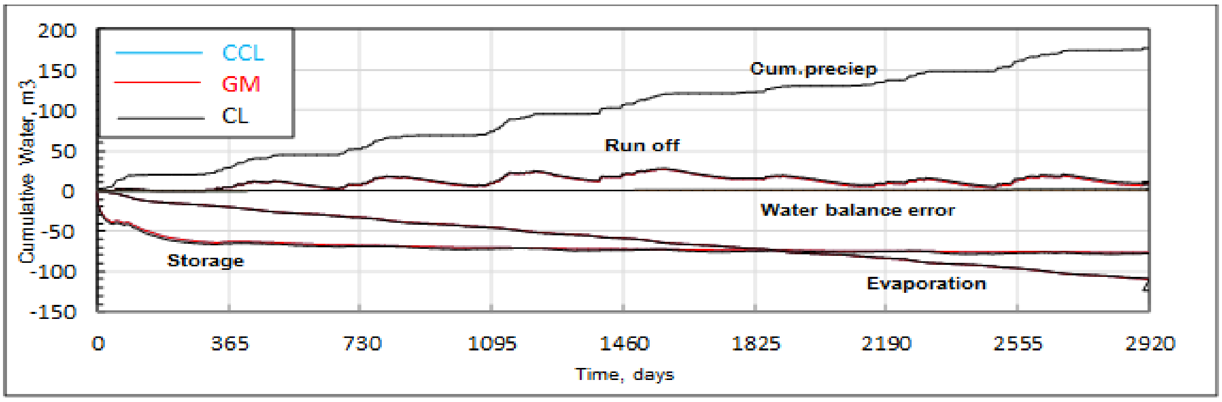

Figure (12): Water balance relation for CCL, GM with one drain and CL with one drain in case with vegetation.

3.4 Impact of construction quality of GM & CL (no vegetation case)
The result showed that increasing the number of drains from one drain to two drains for GM and CL caused an increase in the cumulative daily leak. The cumulative daily leak was increased by about 5 and 33% for the GM and CL lining systems respectively.

CONCLUSION

Three different lining systems were examined namely, compacted clay liner (CCL), geomembrane system (GM) and combined liner (CL). The following conclusions were obtained:

1-The result showed that when changing the side slope of the CCL from 29.74° to 14°, the safety factor has increased by 50%. Further, the effect of changing the thickness of the liner has also been studied. The safety factor was determined for three different thicknesses, namely (0.4, 0.5, 0.7) m. It was found that the liner thickness has very little impact so that it can be neglected. Accordingly the 0.5 m thickness was selected.

2-Hydrological study of CCL was undertaken for three years using VADOSE/W2007 under the influence of the same slope that was previously introduced in the stability investigation and found that the amount of runoff increases with increasing the side slope angle so that it decreased by 61% when changing the angle of side slope from 29.74° to 14°, while the amount of leakage was changed subtly. Lateral side slope for the liner was selected to be 26.56 ° which gave a safety factor of greater than 1.5 and an acceptable leakage value of water

3-The stability was also evaluated for the GM under the same mentioned side slopes and found that the safety factor has increased by 6%.

4- The impact of vegetation and their absence were also studied. The results shown that the leakage was reduced by 9% when having the vegetation cover overlying CCL. The leakage was reduced by 3% in the case of GM with one drain and leakage was reduced in CL with one drain by 13%.

5- The study showed that the minimal amount of leakage was achieved when using CL, CCL and then GM.

6-When increasing the number of drains in each of CL and GM this caused an increased leakage by about 5 and 33% respectively.

7-As a major conclusion is that a landfill could be constructed without a bottom liner system or leaching collection and removal system installed in case of CL with one drains whether having the vegetation cover or not. On the other hand, the GM and CCL systems might be constructed with a bottom liner system in addition to the leaching collection and removal system because the cumulative leak was greater than 10 mm/year [11].

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