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Design and evaluation of side slope stabilization for waste landfills by geosynthetic separation boxes

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ABSTRACT: Geosynthetic separation boxes made from recycled polymeric materials were designed to increase the stability of the steeply sloping sides of waste landfills and improve waste storage efficiencies. The inner sides of the boxes are open and they can be filled with sand, soil, rubble or other materials, to fix them to the side slopes of waste landfills. To evaluate the advantages of geosynthetic separation box plates, index tests were done, comparing geonet composites and geosynthetic separation boxes. Hydraulic and friction properties of geosynthetic separation box plates were better than those of geonet composites. Tensile strength retention ratios of geosynthetic separation box plates exposed to UV light and to leachate were also better. Finally, the properties of geosynthetic separation boxes as geomembranes were compared to requirements derived from theory.

1 INTRODUCTION

Many waste landfills in Korea are built in valleys and have very steeply sloping sides (more than 30°). Large quantities of sand or backfill soils are required to increase the stability of the side slopes. The total volume available for wastes is decreased by as much as that shown by the oblique lines in Figure 1. The resulting smaller waste storage volumes are an important cause of the uneconomic construction of waste landfills.
The use of geosynthetic separation boxes, which are made from recycled waste polymeric materials, reduces the total costs of constructing waste landfills, because they are cheaper to produce. The inner sides of these geosynthetic boxes are open and they can be filled with sand, soil, rubble or other materials to fix them to the slopes of the waste landfills. The use of such materials in the geosynthetic boxes allows good drainage performance as well as increased stability of the sloping sides of waste landfills because of the reinforcement effects.

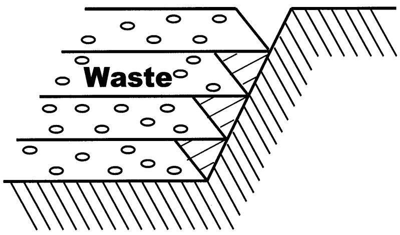


Figure 1. Schematic diagram of waste landfill with geosynthetic separation boxes

In this study, geosynthetic separation boxes of recycled high density polyethylene (HDPE) plates were designed and constructed to increase the stability of the steeply sloping sides of waste landfills and improve waste storage efficiencies. The performance of these plates in waste landfills was examined and their properties assessed by comparing them to the values appropriate for waste landfills obtained from theory.

2 EXPERIMENTAL

2.1 *Manufacture of geosynthetic separation boxes*

Geosynthetic separation boxes were made from recycled HDPE plates with a unit size of 1×1 m^2. The plates were made by injection moulding, and the geosynthetic separation boxes were composed of upper and bottom plates. These two plates were connected by rods and there were many holes in the plates to act as vents for leachates and gas. The boxes, which are connected to each other continuously, are represented in Figure 2.

Sand, gravel and rubble were used as filler materials between the upper and bottom plates of the boxes.

Geonet composite, a nonwoven/geonet/nonwoven structure that is generally applied to the slopes of waste landfills in Korea was used as a basis for comparison with the HDPE(2) of the geosynthetic separation boxes.

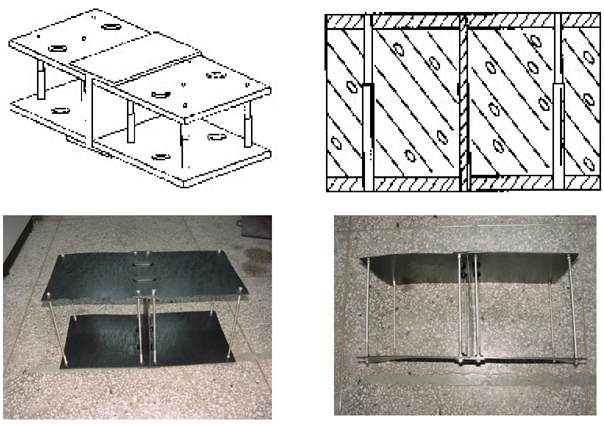


Figure 2. Photographs of geosynthetic separation box

2.2 *Assessment of performance of geosynthetic separation boxes*

To evaluate the advantages of geosynthetic separation boxes, index tests of the plates were done to compare the two cases in which geonet composites and geosynthetics separation boxes were used in the side slopes of waste landfills, as shown in Figure 3, where GCL means geosynthetic clay liner.

Tensile properties, and chemical and UV resistance of the recycled HDPE plates were examined in accordance with ASTM D 638, D 5322 and 4355, respectively.

The hydraulic flows were measured by the amounts of water loss in accordance with ASTM D 4716 for the geonet composite and ASTM D 5493 for the plate of the geosynthetic separation box.

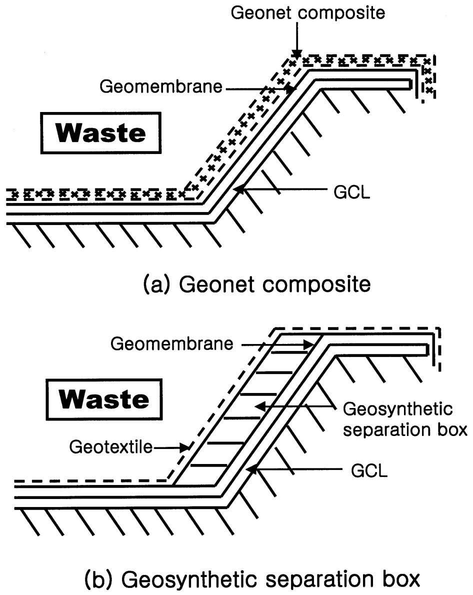


Figure 3. Schematic diagram showing the application of geonet composite and geosynthetic separation boxes to the sloping sides of a waste landfill

3 RESULTS AND DISCUSSION

3.1 *Properties of separation boxes*

3.1.1 *Tensile properties*

Table 1 shows the tensile properties of the recycled and general HDPE plates to be used in the separation boxes.

Table 1. Tensile properties in machine direction of HDPE plates

Tensile Properties / HDPE Plates	Strength (kg/cm^2)	Elongation (%)
HDPE(1)	32.4	603.5
HDPE(2)	36.7	107.4

(1) 3 mm thickness of HDPE plate for geomembranes
(2) 3 mm thickness recycled HDPE plate for geosynthetic separation box

It is apparent that the recycled HDPE plate has higher tensile strength than HDPE(1), but less elongation. This indicates good performance when used as a separation box plate.

3.1.2 *Chemical and UV resistance*

Chemical resistance of the HDPE plates was estimated by the tensile strength retention ratio after 120 days of exposure to leachates with pH values of 3 and 12, and temperatures of 25ºC and 50ºC.

UV resistances by the xenon arc method were also estimated by the tensile strength retention ratio.

Table 2 shows the tensile strength retention ratio of recycled/general HDPE plates and geonet composite.

Table 2. Tensile strength retentions of separation box plate and geonet composite

(a) Chemical resistance

Chemical Resistance / Geosynthetics	Tensile Strength Retention (%)			
	pH 3		pH 12	
	25 °C	50 °C	25 °C	50 °C
HDPE(2)	92.6	88.2	91.2	86.4
Geonet Composite	92.4	88.6	92.6	88.2

(b) UV resistance

UV Resistance / Geosynthetics	Tensile Strength Retention (%)
HDPE(2)	92.4
Geonet Composite	90.6

As the tables show, the tensile strength retention ratios of HDPE(2) for geosynthetic separation boxes were better than for those of geonet composite.

Hydraulic flows were measured by the amounts of water loss with and without filling materials. The permittivity of HDPE(2) plates with holes (details of which are explained in Section 3.2.2) was better than that of geonet composite.

The friction properties of HDPE(2) plate and geonet composite were not good because of their specified surface structures, but those of HDPE(2) were better than those of geonet composite. The nonwoven geotextiles layer of the geonet composite was damaged by friction and this is the main cause of its reduced frictional properties.

Finally, it was apparent that the HDPE(2) of the geosynthetic separation boxes has many advantages as described above for application to the steep side slope of waste landfills. However, further performance tests of geosynthetic separation boxes must be made to confirm these results over longer periods.

3.2 *Properties when applied to waste landfills*

The properties of geosynthetic separation boxes of HDPE(2) when applied to the slopes of waste landfills were estimated by comparing with the theoretical requirements for tensile strength and coefficient of permeability in waste landfill conditions.

3.2.1 *Tensile strength of separation boxes*

For an external load W, and slope angle β for waste landfills, the breaking force of the separation box plate, consisting of the driving force and the resisting force against the driving force, are W sin β and F, respectively, as shown in Figure 4. Here, the factor of safety (FS) means the ratio of W sin β to F in Equation (1).

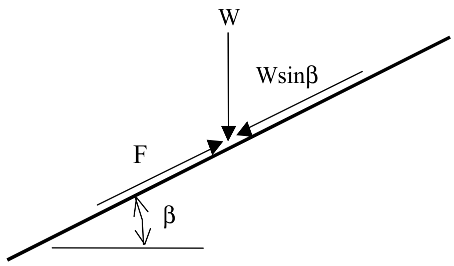


Figure 4. Schematic diagram of acting loads in waste landfills

$$FS = \frac{resisting \cdot force}{driving \cdot force} = \frac{F}{W \sin \beta} \quad (1)$$

If we consider the following installation conditions, the driving and resisting forces are described by Equation (1)

* slope angle(β)
: 15°, 30°, 45°, 50°

* height of waste landfill
  : 3 m, 5 m, 10 m, 20 m, 50 m, 100 m
* density of wastes: 1.4 t/m^3
* weight of final covering:
  vegetation layer + drainage layer = 1 m×1.7 (t/m^3),
  compaction layer = 0.6 m×2 (t/m^3)
* factor of safety: 1.5
  – driving forces:
  1400 kg/m^3×height of waste landfill
  + (weights of vegetation and drainage layers) × sin β
  – resisting forces = 1.5×driving forces

Table 3 represents the required tensile strength of HDPE(2) plates of geosynthetic separation boxes for the given slope angles and heights of waste landfills. For example, the minimum tensile strength of an HDPE(2) plate of a geosynthetic separation box must be 1.05 kg/cm^2 if the slope angle is 45°and height of waste landfill is 5 m.

Table 3. Tensile strength (kg/cm^2) of separation box plate with slope angle and height of waste landfills

		Height of Waste Landfill					
		3 m	5 m	10 m	20 m	50 m	100 m
Slope Angle	15°	0.28	0.38	0.66	1.20	2.83	5.55
	30°	0.53	0.74	1.27	2.32	5.47	10.72
	45°	0.75	1.05	1.79	3.28	7.73	15.16
	50°	0.82	1.14	1.94	3.55	8.38	16.42

3.2.2 *Numbers of holes in separation box plate*

To achieve excellent permeability for the geosynthetic separation box, it is necessary to maintain the optimum hole size in the plate of this box.

The minimum area of the optimum hole was calculated by having regard to the standard permittivity of waste landfills in Korea, which is required to be greater than 1×10^{-2} cm/s.

In this study, the minimum areas of the optimum holes per unit area (1m×1m) of the HDPE(2) plate were calculated by considering the following permittivity ranges:

– for sand: 1×10^0 cm/s ~ 1×10^{-3} cm/s
– for gravel: 1×10^2 cm/s ~ 1×10^{-1} cm/s
– for filled materials: 1×10^{-1} cm/s

The thickness, diameter of hole, and distance between separation boxes are designated A, B and C, respectively, in Figure 5.

The flux of this model can be written as follows from Darcy's law.

$$v = k \cdot i \quad (2)$$

$$Q = v \cdot A \quad (3)$$

$$Q = k \cdot i \cdot A \quad (4)$$

where, v: discharge velocity (cm/s), k: permittivity (cm/s), i: hydraulic gradient, Q: flux (cm^3/s), A: unit area (cm^2)

For hydraulic gradients of two or five with the above conditions, v is constant even if k decreases, and this is because of the increase in i. Minimum numbers and areas of holes, with hole diameter and hydraulic gradient of unit plate in the separation box, are shown in Table 4.

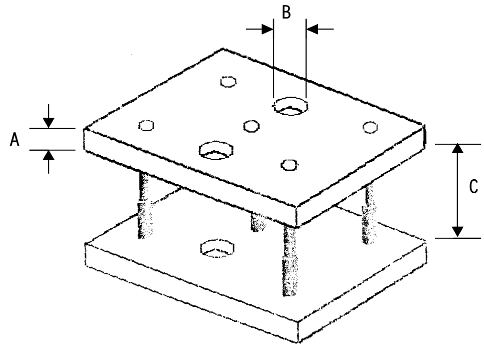


Figure 5. Configuration of separation box with drainage holes

Table 4. Minimum number and area of holes of unit plate in the separation box with diameter of hole and hydraulic gradient

Hydraulic Gradient	2	5
Area (cm)	10000	10000
k (cm /s) - Drainage Layer	1.0E–01	1.0E–01
Acceptable k(cm /s)[1)]	1.0E–02	1.0E–02
Hole Diameter (cm)	1.0	2.0
Discharge(cm /s)[2)]	2000.0	5000.0
First v(cm /s)	0.2	0.5
Acceptable Discharge (cm /s)[3)]	200	500
Minimum Area (cm)[4)]	1000	1000
Fraction of Holes (%)	10	10
Minimum Numbers of Holes	1273	1273

1) standard permittivity
2) flux of drainage layer
3) flux through separation box
4) cross-sectional area of drainage layer with flux through separation box

The minimum numbers of holes per unit plate in the separation box with permittivity and fraction of holes are represented in Table 5. A factor of safety value of 2.0 was adopted to take into consideration the clogging of holes of the unit plates in the separation box.

Table 5. Minimum numbers of holes per unit plate in the separation box with permittivity and fraction of holes

Permittivity (cm/s)	0.05	0.11	0.5	1
Fraction of Holes (%)	20	10	2	1
Hole Diameter, 1 cm	2547	1273	255	127
Hole Diameter, 1.5 cm	1132	566	113	57
Hole Diameter, 2 cm	637	318	64	32
Hole Diameter, 3 cm	283	141	28	14
Hole Diameter, 5 cm	102	51	10	5

From Table 5, it is possible to maintain permittivity in the range of 5.0×10^{-2} ~ 1.0×10^{-1} by making 500 ~ 1,132 holes per unit area of the separation box with hole diameter of 2 cm.

It seems reasonable that the fraction range of holes should be 10 ~ 20% when we consider the permittivity range of sands, which is 5.0×10^{-1} ~ 1.0×10^{-1}.

3.2.3 *Minimum required strength of separation box under load by filled materials*

Figure 6 shows a schematic diagram of a waste landfill slope with a geosynthetic separation box. Figure 7 shows the slope angles of the HDPE(2) plates of the separation box, where the slope angle of the separation box is β.

The following assumptions were used to calculate the loads from the filled materials.

* filled materials: sand
* density of sand: 1.6 ton/m^3 (dry weight)
  - general range of dry-weight density of sand: 1.47 ~ 1.63 ton/m^3
* no water in the drainage layer before landfill
* slope angle of separation box (β): 30°

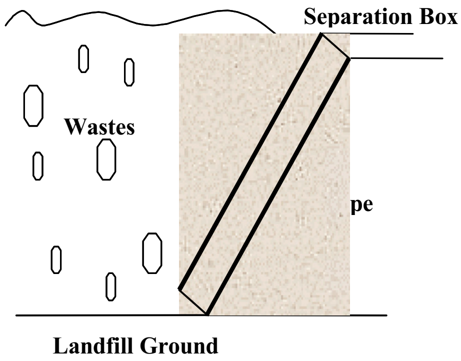
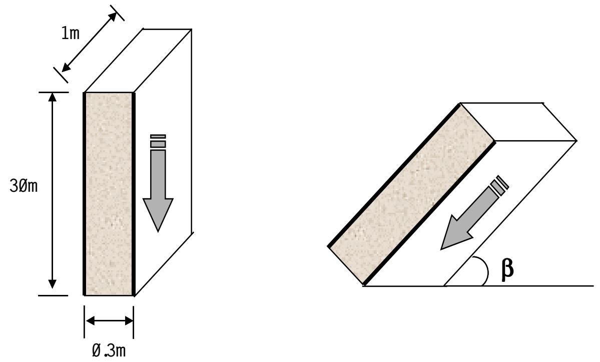


Figure 6. Schematic diagram of waste landfill slope with geosynthetic separation box



(a) (b)

Figure 7. Slope angles for HDPE(2) plate of geosynthetic separation box: (a) 90º, (b) 45º

The minimum required strengths of unit plate of a separation box were determined for the following lengths of slope and slope angles.

* length of slope: 10 m, 30 m, 50 m
* slope angle: 15º, 30º, 45º, 50º
* unit weight of filled materials: sand (1.6 ton/m^3) and gravel (2.0 ton/m^3)

Table 6 shows the minimum required strength with length of slope and slope angle for sands and gravels.

For example, in Table 6 (a), the minimum required strength of the unit plate of the separation box should be 6.13 kg/cm^2 for slope length 50 m and slope angle 50º. In Table 6 (b), the minimum required strength of the unit plate of the separation box should be 7.66 kg/cm^2 for slope length 50 m and slope angle 50º.

From the above analysis, it is seen that the geosynthetic separation box made of recycled HDPE plate has excellent performance when applied to waste landfill slopes.

Table 6. Minimum required strength(kg/cm^2) with length and angle of slope for sands and gravels

(a) for sand (1.6 ton/m^3)

Slope Angle \ Slope Length	10 m	30 m	50 m
15°	0.41	1.24	2.07
30°	0.80	2.40	4.00
45°	1.13	3.39	5.66
50°	1.23	3.68	6.13

(b) for gravel (2.0 ton/m^3)

Slope Angle \ Slope Length	10 m	30 m	50 m
15°	0.52	1.55	2.59
30°	1.00	3.00	5.00
45°	1.41	4.24	7.07
50°	1.53	4.60	7.66

4 CONCLUSION

To summarize the considerations stated above, we conclude the following:

(1) Recycled HDPE showed good tensile strength and chemical and UV resistance, as well as hydraulic and friction properties in comparison to those of HDPE for geomembranes for use in waste landfills.

(2) The recycled HDPE plate is an excellent material for geosynthetic separation boxes for stabilizing the side slopes of waste landfills.

(3) It is very reasonable to apply geosynthetic separation boxes instead of geonet composites to very steeply sloping sides of waste landfills, especially in Korea.

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