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30 JUL 2002

- 1 -

**CLAY LINER INCLUDING CLAY-POROUS INNER SHEET
MATERIAL FOR CLAY EXTRUSION THERE THROUGH
UPON CLAY HYDRATION AND SWELLING**

FIELD OF THE INVENTION

5 The present invention is directed to an
improved, flexible geosynthetic clay liner that is an
effective water barrier for ponds, lagoons, waste
water containment areas, and for lining concrete
surfaces such as concrete plaza decks, concrete
10 foundation walls, and the like. More particularly,
the present invention is directed to a geosynthetic
clay liner comprising two fabric layers and an
intermediate layer of water-swellable clay, such as a
sodium montmorillonite clay, wherein the two fabric
15 layers are structurally secured to surround an
intermediate layer of clay, in any manner, such as by
gluing, compression (U.S. 5,584,609) or by sewing or
needle-punching the fabric layers together to confine
the clay therebetween. In accordance with the present
20 invention, one of the fabric layers, in contact with
the pond or lagoon bed, earthen surface, or foundation
wall, includes an open structure that is sufficiently
open to permit the extrusion of the clay therethrough
when the clay becomes hydrated and swells. The
25 hydrated clay and some water extrudes through the open



166166

- 2 -

fabric structure and contacts an adjacent surface that it is applied against, e.g., a pond or lagoon bed, earthen surface, or concrete foundation wall, thereby blocking the lateral migration of water between the adjacent surface, e.g., concrete foundation wall, and the liner to prevent that water from finding a path through the surface to be protected.

BACKGROUND OF THE INVENTION AND PRIOR ART

The present invention relates to clay geosynthetic liners which are used to form water barriers. The geosynthetic clay liners are useful for lining a surface for protecting that surface against the penetration of water therethrough, particularly for protecting water holding areas, waste water holding areas, concrete surfaces, and the like, such as horizontal plaza decks and vertical concrete foundation walls.

The use of water-swellable smectite clay, such as sodium bentonite, to create a low permeability barrier in landfills and ponds is well known. Bentonite is a clay material that occurs naturally and it expands when hydrated upon absorption of water. When the bentonite absorbs water and expands, it is capable of forming a barrier with low permeability to water migration if the bentonite is properly contained. The geosynthetic clay liners of the present invention rely on incomplete clay containment via extrusion of water-containing, water-swellable clay therethrough upon hydration to prevent the lateral migration of water under the liners.

- 3 -

Geosynthetic clay liners primarily are made with two sheets, e.g., a carrier sheet and a cover sheet, surrounding a layer of water-swellable clay. The primary backing or carrier sheet is normally the more durable material and the liner is often disposed such that the carrier sheet lies against the surface to be protected against water penetration. The cover sheet, also referred to as scrim, is normally less durable than the carrier sheet. The product, including a layer of water-swellable bentonite clay disposed between the two sheets (cover sheet and carrier sheet) is often referred to as a geosynthetic clay liner or GCL.

In order for the water-swellable clay, such as sodium bentonite, to create an effective water barrier, it must be properly contained, such as contained between two sheets - a carrier sheet and a cover sheet. The bentonite may be held in place by glue applied to the carrier sheet; by compression of two sheets surrounding a wet layer of bentonite, e.g., this assignee's U.S. Patent No. 5,584,609, (hereby incorporated by reference); by needle-punching the cover sheet to the carrier sheet; or by stitching the carrier sheet to the cover sheet, or a combination thereof. The sheets may be manufactured from durable woven or non-woven materials or sheets that do not permit the bentonite to migrate through the material.

In accordance with this Assignee's prior U.S. Patent No. 5,350,255, it is known to manufacture a geosynthetic clay liner, for use in landfills, that includes an open structure in the fabric edges for

- 4 -

migration of bentonite clay where two geosynthetic clay liners overlap. As indicated in the '255 patent, the open weave is confined to the overlap portions of the GCLs to prevent water penetration in the areas of GCL overlap, and the majority of the GCL has a more closed weave for proper clay confinement in order to maintain the low permeability needed in a landfill environment.

In accordance with the prior art, by properly containing the bentonite between two sheets that do not allow for migration of the bentonite, the bentonite has been properly contained and, upon hydration by water, the bentonite will swell and form an effective water barrier. The geosynthetic clay liners of the present invention, on the other hand, provide for controlled migration of water-swellable clay and clay-contained water through an "open" fabric side to prevent lateral migration of water behind the liners.

SUMMARY OF THE INVENTION

A geosynthetic clay liner (GCL) is provided that includes a layer of water-swellable smectite clay, e.g., sodium montmorillonite, disposed between a carrier sheet and a cover sheet. An inner sheet, disposed against the surface to be protected against water penetration - either the carrier sheet or the cover sheet - is made of material having a more open structure that allows hydrated bentonite to migrate through it. The other, e.g., outer sheet, includes a more closed structure and, therefore, precludes bentonite migration through it. The GCL can be held

- 5 -

together in any manner known, e.g., by adhesively affixing the clay to the sheet material layers, by high pressure compression (45-85 pounds per lineal inch) of the fabrics together surrounding a wet layer
5 of water-swellaable clay (e.g., 20-50% by weight water, based on the dry weight of the clay); or by needle-punching or stitching the sheet material layers together surrounding the intermediate clay layer.

Upon hydration, the smectite clay swells to
10 form the barrier. Because the outer sheet or fabric includes a relatively more closed structure than the inner sheet, the bentonite is substantially contained and does not substantially migrate through the outer sheet. Preferably, the outer sheet material layer,
15 when subjected to a pressure of 54.6 psi, does not permit migration of wet clay therethrough more than about 0.01 gm/cm². More preferably less than 0.006 gm/cm² wet clay extrudes through the outer sheet material layer at 54.6 psi. However, because the
20 inner sheet is more open or is more loosely woven, the hydrated bentonite substantially migrates through it in a minimum amount of at least about 0.15 grams (wet basis) per cm², preferably at least about 0.2 grams/cm² when subjected to a pressure of 54.6 pounds per square
25 inch (psi), as described in more detail hereinafter. The extruded, hydrated clay that migrates through the inner sheet engages the adjacent surface to be protected, e.g., a pond or waste water lagoon earthen surface or a concrete foundation wall. The
30 substantial migration of the bentonite through the inner sheet ensures that an effective seal is created, to protect against lateral water movement between the

geosynthetic clay liner and the adjacent surface to be protected.

The open structure of the inner fabric sheet may be obtained by employing a looser weave (i.e., lower warp yarn count) than the closed structure of the outer sheet (higher warp yarn count). In particular, it has been found that the surface of the inner sheet should have at least about 5%, preferably at least about 6%, of its surface area as void or open area. If a non-woven geotextile is used as the inner fabric sheet material, the weight of the geotextile, in order to provide at least 5% void or open area in its surface, generally should be in the range of about 100 g/m² to about 200 g/m², preferably about 125 g/m² to about 175 g/m². However, the basis weight can vary substantially both above and below the 100 g/m² to 200 g/m² range, particularly when perforated or slit to provide more clay migration, so long as the hydrated clay extrudes through the open fabric sheet in an amount of at least 0.15 g/cm², preferably at least about 0.2 g/cm² when subjected to a pressure of 54.6 psi. The more open structure of woven inner sheet materials also may be obtained by a perforation or slitting process that creates a structure that will allow for substantial water-swellable clay migration through it.

The method of using a more loosely woven or more open inner sheet (e.g., having a lower warp yarn count) is preferred but the looser weave and the perforation/slitting methods are alternative embodiments that are within the scope of the present

- 7 -

invention. The needle-punching and perforation/-slitting methods are especially adaptable for geosynthetic clay liners made without gluing the bentonite to one of the sheets (i.e., compression consolidated or a needle-punched liner). The loosely woven and perforated/slitted methods provide the open structure for the inner sheet and the term "open" is meant to indicate sufficient open area for ease of hydrated clay migration through the sheet material in an amount of at least 0.15 g/cm^2 , preferably at least 0.2 g/cm^2 , when subjected to a pressure of 54.6 psi (376.5 kN/m^2). Regardless of the percent open area, the inner sheet material layer should extrude at least 0.15 g/cm^2 of hydrated clay composition (clay and water) when subjected to a pressure of 54.6 psi, preferably at least 0.2 g/cm^2 . In contrast, the term "closed" is meant to indicate a structure that does not permit bentonite migration therethrough in an amount of more than 0.01 gm/cm^2 at a pressure of 54.6 psi, e.g., a tightly woven sheet material layer.

Accordingly, one aspect of the present invention is to provide a clay liner comprising an inner sheet material layer, an outer sheet material layer, and a layer of water-swellaible smectite clay therebetween, wherein said inner sheet material layer includes a more open structure than the outer sheet material layer, such that upon hydration of said clay, the clay extrudes through the inner sheet material layer, but not through the outer sheet material layer,

to protect against lateral migration of water between the surface being protected and the outer surface of the inner sheet material layer.

Another aspect of the present invention is to provide a plurality of clay liners that can be disposed against a sloped, vertical, or horizontal surface side-by-side, without overlap, wherein the clay liner includes an open fabric disposed against the surface to be protected against water penetration, such that upon hydration of the clay contained within the liner, the clay will extrude through the open fabric to stop lateral migration of water that penetrates to the protected surface from between adjacent liners.

The above and other aspects and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments, taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of one embodiment of the clay liner, e.g., geosynthetic clay liner (GCL) of the present invention;

FIG. 2 is a partially broken-away top view showing a plurality of the GCLs of the present invention disposed against a concrete foundation wall or earthen surface applied by overlapping adjacent GCLs;

FIG. 3 is a side view showing a plurality of the GCLs of the present invention disposed on top of a horizontal concrete plaza deck applied side-by-side without overlap;

5 FIG. 4 is a perspective view of another embodiment of the GCL of the present invention having an "open" side formed by slitting an inner sheet material layer to provide at least 5% open area in the surface of the inner sheet material layer; and

10 FIG. 5 is a perspective view of a slitting apparatus forming slits in the GCL of FIG. 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Like reference numerals will be used to refer to like or similar parts from Figure to Figure
15 in the following description of the drawings.

FIG. 1 is an illustration of the geosynthetic clay liner 10 including an outer cover sheet 11, a water-swellable smectite clay, e.g., sodium bentonite, layer 12 and an inner carrier sheet
20 13. All of the Figures and the description below depict the cover sheet as the outer sheet when installed and the carrier sheet as the inner sheet that is disposed against the surface to be protected, when installed.

25 The outer or cover sheet 11 is more tightly woven or has a more closed structure than the inner or carrier sheet 13. For woven fabrics, the outer or cover sheet 11 has a higher warp count than the warp

count of the inner or carrier sheet 13, or the inner sheet 13 is perforated, or slit to include at least 5%, preferably at least about 6%, up to about 25% void or open area in the surface, preferably about 8% to about 20%, more preferably about 10% to about 15% void area in its outer surface. The inner sheet can be woven; non-woven, particularly a non-woven synthetic fiber, such as polypropylene; and/or a polymeric sheet material layer, each of which may be friction enhanced in accordance with this assignee's U.S. Patent No. 5,403,126, hereby incorporated by reference. Non-woven sheet materials preferably have a weight in the range of about 100 g/m² to about 200 g/m², at a thickness of about 1/32 inch to about 1/8 inch, and provide at least 5% open area, preferably at least about 6% open area, in their outer surface, along the entire outer surface, more preferably about 125 g/m² to about 175 g/m² at a thickness of about 1/32 inch to about 1/8 inch, to provide at least 5% open area along the entire outer surface of the inner sheet material.

Regardless of the percent open area for both the woven and non-woven inner sheet material layers 13, the inner sheet material layer 13 should be sufficiently "open" such that it extrudes at least about 0.15 grams/cm² of hydrated clay (clay plus water) therethrough when subjected to a pressure of 54.6 psi, preferably at least 0.2 grams/cm² of wet clay, most preferably about 0.3 gm/cm² to 0.5 gm/cm². On a dry weight basis, the amount of clay extruded through the open sheet material layer should be at least about 0.03 gm/cm², preferably at least about 0.04 gm/cm², most preferably about 0.05 gm/cm² to about 0.1 gm/cm².

The more open inner sheet 13 provides for substantial migration of the bentonite 12 inwardly through the inner sheet 13 upon hydration of the bentonite 12 with water.

5 An illustration of the installation of the geosynthetic clay liner 10, like the one shown in FIG. 1, is illustrated against a vertical, concrete foundation wall or earthen surface 20 in FIG. 2, and on top of a concrete plaza deck 22 in FIG. 3.

10 Upon hydration by water, the bentonite layer 12 (preferably about 1/16 inch to about 1/4 inch in thickness) migrates inwardly through the more open inner sheet 13 in an amount of at least about 0.15 gm/cm², preferably at least about 0.2 gm/cm², and
15 engages the surface 20 or 22 to be protected, as illustrated in FIGS. 2 and 3. The expanding and migrating hydrated bentonite composition 12 forms a seal along the surface 20 or 22 to be protected that prevents the lateral migration of water along the
20 surface 20 or 22.

 The preferred material for fabrication of the inner or carrier sheets is fabric woven from polypropylene fibers, such as 80-VOL fabric produced by Synthetic Industries, Inc. of Chatanooga,
25 Tennessee, which may be then slit or needle-punched, that extrudes at least 0.15 gm/cm² of hydrated clay composition when subjected to a pressure of 54.6 psi. The carrier and cover sheets have a thickness from, for example, about 1/32 inch to about 1/4 inch,
30 preferably about 1/16 inch to about 1/8 inch, and, to

- 12 -

achieve the full advantage of the present invention, the inner sheet 13 has a void area of at least about 8% of the surface area.

As shown in FIG. 4, preferably the inner sheet material layer 13 of the geosynthetic clay liner 10 initially has, or can be provided with, at least 5% void area in its outer surface, by slitting or needle-punching to provide slits or holes 24 completely through the inner sheet material layer 13. The optional slits or holes 24 can be formed prior to applying the inner sheet material layer over the clay layer 12 or, preferably, as shown in FIG. 5, are applied through the inner sheet material layer 13 after construction of the geosynthetic clay liner 10. As shown in FIG. 5, a slitting apparatus 26 includes a rotatable slitting bar 27, that carries a plurality of slitting knives 28, and the slitting bar 27 can be rotated via motor 30 to apply a uniform array of slits 24 that are disposed along the entire outer surface of the inner sheet material 13. The slits 24 preferably provide at least 5% void or open area in the outer surface of inner sheet material layer 13, more preferably about 8% to about 15% void or open area.

In the preferred embodiment of the geosynthetic liner, the inner sheet is a polypropylene woven material, 80-VOL from Synthetic Industries, Inc., that extrudes an average of 0.034 gm/cm² at 54.6 psi compared with earlier product from this Assignee (prior art) that extruded 0.0056 gm/cm² at 54.6 psi.

- 13 -

In order to test the wet clay extrusion or migration through the open sheet material 13 (see FIG. 1) five identical clay liner samples were prepared from pieces of a geosynthetic clay liner having a woven polypropylene sheet material inner layer 13 (80-VOL from Synthetic Industries, Inc.), and a non-woven polypropylene, needle-punched outer sheet material layer 11 (GEOTEX 650 from Synthetic Industries, Inc.) that sandwich a layer of granular sodium bentonite clay 12 therebetween such that the total thickness of the clay liner is 0.8 cm when hydrated and 0.6 cm prior to wetting (as received after manufacture). The samples were immersed in distilled water for 72 hours to completely hydrate the samples.

15 **PENETROMETER TEST PROCEDURE**

(CL-700A Pocket Penetrometer And One Inch Clay Collection Adapter Foot CL-701¹ From The Soiltest Products Division Of ELE International)

- 20 A. After the appropriate hydration period, carefully remove the sample from the immersion tub and place onto a flat, level surface.
- 25 B. Weigh the clay collection attachment and record. Attach the clay collection attachment (adaptor foot) to the penetro-

¹ The Clay Collection Adaptor is the CL-701 Adaptor Foot from Soiltest Division of ELE International having a 11.3 mm diameter hole drilled into the lower material contacting center for collection of clay. A 700 psi reading on penetrometer is 54.6 psi because of the lower contact area that results from the drilled hole.

- 14 -

meter and set the penetrometer to 0 psi following the manufacturer's instructions.

- 5 C. Place the penetrometer and clay collection attachment (adaptor foot) vertically on top of the specimen at the approximate center of the 0.1 m² (1.0 ft²) square sample. Holding the penetrometer with the clay collection attachment at a right angle to the test specimen, force the entire apparatus
- 10 (penetrometer and clay collection attachment) into the specimen applying force as necessary. Continue forcing the apparatus into the material until the penetrometer reaches a maximum value (700
- 15 psi).
- D. Record the reading on the scale of the penetrometer.
- E. Carefully pull out the penetrometer and the clay collection attachment, making sure not
- 20 to displace any of the clay on or in the clay collection attachment. Scrape any clay off the surface of the material within the cross-sectional area of the clay collection attachment that extruded during the testing
- 25 procedure, but that may not have been collected in the clay collection attachment. Place this displaced clay in the clay collection attachment.
- F. Carefully remove the clay collection
- 30 attachment from the penetrometer and weigh both the extruded clay and the clay collection attachment.

30 JUL 2002

- 15 -

- 5 G. Place the clay collection attachment and the collected clay in a drying oven. Dry the samples for the appropriate time. Reweigh the samples to determine the moisture content of the sample during the test procedure.
- H. Repeat for a total of five samples.

10 The amount of clay extruded through the 1 cm² opening in the clay collection adaptor is shown in the data of the following Table 1:

TABLE 1

Example No.	Area of Contact (cm ²)	Area Open for Extrusion (cm ²)	Mass of Wet Extruded Material (g)	Mass of Dry Extruded Material (g)	Moisture Content of Extruded Material (%)	Normal Stress (kN/m ²)	Normal Stress (psi)	Mass/Unit Area of Extruded Material (g/cm ²)
1	4.07	1.00	0.31	0.06	396%	376.5	54.6	0.31
2	4.07	1.00	0.31	0.06	387%	376.5	54.6	0.31
3	4.07	1.00	0.23	0.04	427%	376.5	54.6	0.23
4	4.07	1.00	0.45	0.08	444%	376.5	54.6	0.45
5	4.07	1.00	0.41	0.08	440%	376.5	54.6	0.41
AVERAGE	4.07	1.00	0.34	0.06	419%	376.5	54.6	0.34

5

10

30 JUL 2002

30 JUL 2002

- 17 -

While only a selection of specific embodiments of the present invention has been illustrated and described, it will at once be apparent to those skilled in the art that variations may be made within the spirit and scope of the invention. Accordingly, it is intended that the scope of the invention be limited solely by the scope of the hereafter appended claims and not by any specific wording and the foregoing description.

WHAT IS CLAIMED IS:

1. In a geosynthetic clay liner comprising an inner sheet material layer and an outer sheet material layer having a layer of water-swellable smectite clay disposed therebetween, said inner sheet material layer disposed against a surface protected against water penetration, the improvement comprising said inner sheet material layer including a more open structure, across its entire surface, than the outer sheet material layer, such that upon hydration of said clay, the clay extrudes through the inner sheet material layer, but not through the outer sheet material layer.

2. In the geosynthetic clay liner of claim 1, wherein the inner sheet material layer is a woven fabric having a uniformly disposed more open weave than the outer sheet material layer.

3. In the geosynthetic clay liner of claim 1, wherein the inner sheet material layer is a non-woven fabric and is homogeneously more permeable to hydrated clay than the outer sheet material layer.

4. In the geosynthetic clay liner of claim 1, wherein the inner sheet material layer is a polymeric sheet material layer having holes or slits such that at least 5% of its outer surface area is apparent void or open area, such that the inner sheet material extrudes at least 0.015 gm/cm² wetted clay therethrough at a pressure of 54.6 psi.

- 19 -

5. In the geosynthetic clay liner of claim 2, wherein the outer sheet material layer is a non-woven fabric.

6. In the geosynthetic clay liner of claim 2, wherein the inner sheet material layer is a woven fabric having about 8% to about 15% void area, such that the inner sheet material extrudes at least 0.02 gm/cm² at a pressure of 54.6 psi.

7. In the geosynthetic clay liner of claim 4, wherein the outer sheet material layer is a water-impermeable polymeric sheet material layer.

8. In the geosynthetic clay liner of claim 7, wherein the water-impermeable polymeric sheet material layer has a friction enhancing material applied or textured on at least a portion of its outer surface.

9. In the geosynthetic clay liner of claim 3, wherein the outer sheet material layer is a non-woven fabric that extrudes less than 0.01 gm/cm² of wetted clay therethrough at a pressure of 54.6 psi.

10. In the geosynthetic clay liner of claim 3, wherein the outer sheet material layer is a woven fabric that extrudes less than 0.01 gm/cm² of wetted clay therethrough at a pressure of 54.6 psi.

11. In the geosynthetic clay liner of claim 3, wherein the outer sheet material layer is a water-impermeable polymeric sheet material layer.

- 20 -

12. In the geosynthetic clay liner of claim 11, wherein the outer water-impermeable polymeric sheet material layer has a friction enhancing material coated or textured onto at least a portion of its outer surface.

13. In the geosynthetic clay liner of claim 1, wherein the inner sheet material layer includes void or open area in its outer surface of at least 6% and extrudes wetted clay therethrough in an amount of at least 0.015 gm/cm^2 , total weight of clay and water, at 54.6 psi, and the outer sheet material has 0-4% void area in its outer surface, and extrudes wetted clay therethrough in an amount of less than 0.01 gm/cm^2 , total weight of clay and water, at 54.6 psi.

14. In the geosynthetic clay liner of claim 1, wherein the inner sheet material layer includes about 8% to about 15% void or open area in its outer surface, such that the inner sheet material layer extrudes wet clay therethrough in an amount of at least 0.015 gm/cm^2 , total weight of clay and water, at a pressure of 54.6 psi.

15. In the geosynthetic clay liner of claim 14, wherein the inner sheet material layer has a weight of about 100 g/m^2 to about 200 g/m^2 .

16. In the geosynthetic clay liner of claim 15, wherein the inner sheet material layer has a weight of about 125 g/m^2 to about 175 g/m^2 .

- 21 -

17. In the geosynthetic clay liner of claim 16, wherein the outer sheet material layer has a weight of at least about 220 g/m², such that the outer sheet material layer extrudes less than 0.01 gm/cm² wet clay, total weight of clay and water, at a pressure of 54.6 psi.

18. A method of protecting a surface against water penetration comprising disposing the improved geosynthetic clay liner of claim 1 against said surface, with the inner sheet material layer disposed thereagainst.

19. A method of protecting a surface against water penetration comprising disposing the improved geosynthetic clay liner of claim 11 against said surface, with the inner sheet material layer disposed against said surface.

20. A method of protecting a surface against water penetration comprising disposing the improved geosynthetic clay liner of claim 12 against said surface, with the inner sheet material layer disposed thereagainst.

21. The method of claim 19, wherein the surface to be protected is concrete.

22. The method of claim 20, wherein the surface to be protected is concrete.

- 22 -

23. The method of claim 21, wherein the surface to be protected is an earthen surface, disposed beneath a water-holding area.

24. The method of claim 22, wherein the surface to be protected is an earthen surface, disposed beneath a waste-water holding area.

25. A composite structure comprising a concrete wall or concrete deck having disposed thereagainst the geosynthetic clay liner of claim 1, wherein the more open, inner sheet material layer contacts the concrete wall or concrete deck.