GEOTEXTILES AND GEOMEMBRANES: PROPERTIES, PRODUCTION AND ENGINEERING APPLICATIONS

[1]U. P. Kelechi & [2]O. C. Okeke
[1&2]Department of Geology,
Federal University of Technology, Owerri,
Imo State, Nigeria.
[1]kkbrightone@gmail.com, +2348063604998
[2]ositachris@yahoo.com, +2347036394020

ABSTRACT: Geosynthetics is the term used to describe a range of plannar product which is manufactured from a polymeric material used with soil, rock, earth or other geotechnical related materials engineering related materials as an integral part of man-made projects, structure or system and for Civil Engineering construction works. Geosynthetics such as Geotextiles, Geomembrane are newly emerging field in the civil engineering and other fields, offer great potential in varied areas of applications globally. Geotextiles play a significant part in modern pavement design and maintenance techniques, while Geomembrane used as an environmental, geotechnical, hydraulic, transportation, and private development applications as liners and covers. The growth in their use worldwide for transportation, liners applications in particular, has been nothing short of phenomenal. Geosynthetics are ideal materials for infrastructural works such as roads, harbors and many others. They have a bright future, thanks to their multifunctional characteristics. The paper provides an overview of various natural as well as synthetic textile fibres used and engineering application.

KEYWORDS: Geosynthetics, Geotextile, Geomembrane, Polymers, Fiber, Liners, Reinforcement.

I. INTRODUCTION

Geosynthetics is the term used to describe a range of polymeric products used for Civil Engineering construction works. The term is generally regarded to encompass eight main products categories. They include geotextiles, geogrids, geonets, geomembrane, geosynthetic clay liners, geofoam, geocells and geocomposite. The most popular geosynthetics used are the geotextiles and geomembrane (ASTM 1994).

Geosynthetics have proven to be among the most versatile and cost-effective ground modification materials. Their use has expanded rapidly into nearly all areas of civil, geotechnical, environmental, coastal, and hydraulic engineering.

A. **Types of Geosynthetics**

Geosynthetics are usually produced either in sheets or in fabric filaments (fibers) with the major variations in their composition, thickness and strength. These are then further worked upon in the production process to produce the construction geosynthetics group. The different types of this geosynthetics group products are geotextiles (geofabrics), geogrids, geonets, geomembranes, geosynthetic clay liners (GCL), geopipes or geotubes, geocells, geofoams, drainage/infiltration cells and geocomposites.

Below is the description of the above listed materials:

i. **Geotextile or Geofabrics**: Geotextiles form one of the two largest groups of geosynthetic materials. They are indeed textiles in the traditional sense, but consist of synthetic fibers (all are polymer-based) rather than natural ones such as cotton, wool, jute. Thus, biodegradation and subsequent short lifetime is not a problem. These synthetic fibers are made into flexible, porous fabrics by standard weaving machinery or they are matted together in a random nonwoven manner. Some are also knitted. The major point is that geotextiles are porous to liquid flow across their manufactured plane and also within their thickness, but to widely varying degree (Wikipedia, 2011).
ii. **Geogrids**: They are unitized woven yarns or bonded straps. Geogrids consist of heavy strands of plastic materials arranged as longitudinal and transverse elements to outline a uniformly distributed and relatively large and grid like array of apertures in the resulting sheet. These apertures allow direct contact between soil particles on either side of the sheet. (Bergado et al, 2005). Geogrids are (a) either stretched in one or two directions for improved physical properties, (b) made on weaving or knitting machinery by standard textile manufacturing methods, or (c) by bonding rods or straps together.
iii. **Geonets:** A geosynthetic material consisting of parallel sets of intersecting ribs that form a three-dimensional net-like material. They are used to improve drainage by creating a “thin” plane for water to travel through. (Kercher, 2011).
iv. **Geomembranes:** A geosynthetic material that is virtually waterproof when used as a fluid barrier. The materials themselves are impervious thin sheets of rubber or plastic

material. A common application of this is a landfill liner, cover of liquid or solid storage or disposal facilities.

v. **Geocomposite:** A material made up of a combination of geosynthetic materials that is used to improve performance by combining the benefits of two types of geosynthetics. There are virtually hundreds of different types of geosynthetic products available on the market today. Please remember that all geosynthetic materials work in some type of application, but no geosynthetic works in all applications.

vi. **Geosynthethic clay liners**: These are the newest subset within geosynthethic materials. They are roll of factory fabricated thin layers of bentonite clay sandwiched between two geotextiles or bounded to a geomembrane. Structural integrity of geosynthetic clay liners is maintained by needle punching, stitching or adhesive bonding. Used as a composite component beneath a geomembrane or by themselves as a primary or secondary liners providing hydraulic barriers.

vii. **Geopipes:** Perharps the original geosynthetic material still available and in use is buried plastic pipe. Also the critical nature of leachate collection pipes coupled with high compressive loads makes geopipe a bonifide member of geosynthetic family. Commonly used for drainage.

II. LITERATURE REVIEW ON PRODUCTION, PROPERTIES AND ENGINEERING APLICATION OF GEOTEXTILES

A. Production

Geotextiles are made from polypropylene, polyester, polyethylene, polyamide (nylon), polyvinylidene chloride, and fiberglass. Polypropylene and polyester are the most used. Sewing thread for geotextiles is made from Kevlar or any of the above polymers. The physical properties of these materials can be varied by the use of additives in the composition and by changing the processing methods used to form the molten material into filaments. Yarns are formed from fibers which have been bundled and twisted together, a process also referred to as spinning (this reference is different from the term spinning as used to denote the process of extruding filaments from a molten material.) Yarns may be composed of very long fibers (filaments) or relatively short pieces cut from filaments (staple fibers) (Paul Guyer J, 2009).

Exposure to sunlight degrades the physical properties of polymers. The rate of degradation is reduced by the addition of carbon black but not eliminated. Hot asphalt can approach the melting point of some polymers. Polymer materials become brittle in very cold temperatures. Experience with geotextiles in place spans only about 30 years. All of these factors should be considered in selecting or specifying acceptable geotextile materials. Where long duration integrity of the material is critical to life safety and where the in-place material cannot easily be periodically inspected or easily replaced if it should become degraded (for example filtration and/or drainage functions within an earth dam), current practice is to use only geologic materials (which are orders of magnitude more resistant to these weathering effects than polyesters) (Andrawes et al, 1982).

B. Properties of Geotextiles

The characteristics of geotextiles are broadly classified as:

1. **Physical properties:** Specific gravity, Weight, Thickness, Stiffness, Density.
2. **Mechanical properties:** Tenacity, Tensile strength, Bursting strength, Drapability, Compatibility, Flexibility, Tearing strength, Frictional resistance.
3. **Hydraulic properties:** Porosity, Permeability, Permittivity, Transitivity, Turbidity /soil retention, Filtration length etc.
4. **Degradation properties:** Biodegradation, Hydrolytic degradation, Photo degradation, Chemical degradation, Mechanical degradation (Tripti et al 2012)

C. Types of Geotextile

Figure 1: Geomembrane Types (Agrawal, B. J. 2011)

1. **Woven Geotextiles:** The warp yarns, which run parallel with the length of the panel (machine direction), are interlaced with yarns called fill or filling yarns, which run perpendicular to the length of the panel. Woven construction produces geotextiles with high strengths and moduli in the warp and fills directions and low elongations at rupture. Woven construction produces geotextiles with a simple pore structure and narrow range of pore sizes or openings between fibers. Woven geotextiles are commonly plain woven, but are sometimes made by twill weave or leno weaves (a very open type of weave). Woven geotextiles can be composed of monofilaments or multifilament yarns. Multifilament woven constructions produce the highest strength and modulus of all the constructions but are also the highest cost. A monofilament variant is the slit-film or ribbon filament woven geotextile (Agrawal, B. J. 2011).

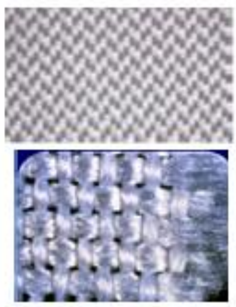

Figure 2: Woven Geotextile (Agrawal, B. J. 2011)

2. **Nonwoven Geotextiles:** These are formed by a process other than weaving or knitting, and they are generally thicker than woven products. These geotextiles may

be made either from continuous filaments or from staple fibers. The fibers are generally oriented randomly within the plane of the geotextile but can be given preferential orientation. In the spun-bonding process, filaments are extruded, and laid directly on a moving belt to form the mat, which is then bonded by one of the processes described below.

- **Needle Punching:** Bonding by needle punching involves pushing many barbed needles through one or several layers of a fiber mat normal to the plane of the geotextile. The process causes the fibers to be mechanically entangled.
- **Heat Bonding:** This is done by incorporating fibers of the same polymer type but having different melting points in the mat, or by using heterofilaments, that is, fibers composed of one type of polymer on the inside and covered or sheathed with a polymer having a lower melting point.
- **Resin Bonding:** Resin is introduced into the fiber mat, coating the fibers and bonding the contacts between fibers.
- **Combination Bonding:** Sometimes a combination of bonding techniques is used to facilitate manufacturing or obtain desired properties (Agrawal, B. J. 2011).

Figure 3: Non Woven Geotextile (Agrawal, B. J. 2011)

3. **Knitted Geotextiles:** Knitted geosynthetics are manufactured using another process which is adopted from the clothing textiles industry, namely that of knitting. In this process interlocking a series of loops of yarn together is made. An example of a knitted fabric is illustrated in figure. Only a very few knitted types are produced. All of the knitted geosynthetics are formed by using the knitting technique in conjunction with some other method of geosynthetics manufacture, such as weaving (Agrawal, B. J. 2011).

Figure 4: knitted Geotextiles (Agrawal, B. J. 2011)

D. Engineering Applications of Geotextile

Civil engineering works where geotextiles are employed can be classified into the following categories:

1. **Erosion Control:** Geogrids installed on steep slopes prevent in washing soil particles from surface. Geo-textiles allow the water to pass through but resist the fine soil migration. After vegetation, which provides erosion control of slope, becomes grown, the geogrid will decompose after several years (Agrawal, B. J. 2011).
2. **Separation:** Geo textiles can be used as separator between subsoil and aggregate layer of roads. This protects the aggregate layer from sinking in the subsoil. At the same time it is permeable to water (Agrawal, B. J. 2011).

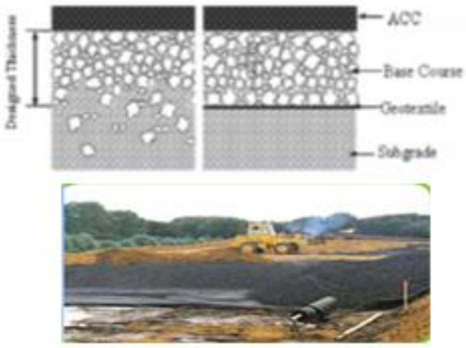

Figure 5: Geotextile Used For Separation (Agrawal, B. J. 2011)

3. **Filtration:** The filtration function of a geotextile serves the same purpose as the separation function, but under different circumstances. Geo textile has become a solution for draining out the accumulated water from areas like coal yards. It is filter media to retain soil particles of backfill material in place, while it allows the release of accumulated hydraulic pressure (Agrawal, B. J. 2011).

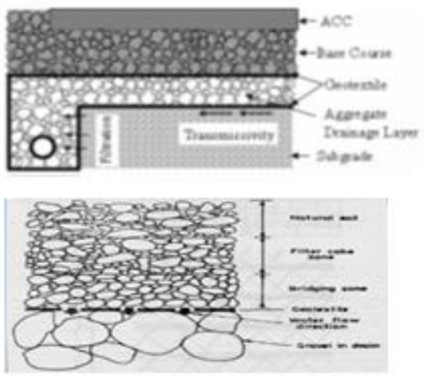

Figure 6: Geotextile Used For Filtration (Agrawal, B. J. 2011)

4. **Protection:** Soil waste and hazardous landfill structures are designated with impervious geo-membrane layer along with geo textile thus ensuring that no ground water contamination takes place. It also acts as drainage gallery. It is used in the thermal power stations for disposing off the fly ashes in the ash-ponds constructed

with impervious geo-membrane layer along with geo textile that protects the membrane from punching and soil polluting (Agrawal, B. J. 2011).

5. **Drainage:** Drainage function is defined as "The collecting and transporting of ground water and/or other fluids in the plane of the geotextile". It is the ability of the geotextile to drain fluids on its own, meaning that it is not part of a drainage system, but is the drainage system itself (Agrawal, B. J. 2011).
6. **Paving:** Geotextile provides several benefits to pavements. It acts as a stress relieving interlayer. It retards the reflection cracks, reduces road maintenance costs, increases the road life and improves the pavement service ability (Agrawal, B. J. 2011).
7. **Reinforcement:** Soils have relatively low tensile strength so that they are not able to transfer all of forces arising in a structure when it is loaded. Geosynthetics materials will form a base composite by grainy material interlocking which is effective even on the substrates formed by peat or soft silt (Agrawal, B. J. 2011).

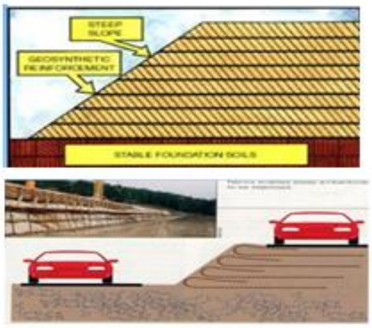

Figure 7: Geotextile Used As Reinforcement (Agrawal, B. J. 2011)

E. CASE HISTORY: MARGARET EKPO INTERNATIONAL AIRPORT BYPASS, CROSS RIVER, NIGERIA.

- **Main Contractor**: Sermatech Nig Ltd February 2013.
- **Location/ Project**: Margaret Ekpo Int. Airport Bypass Nigeria 213,695sqm Stratec G30PP
- **Problem Faced**: Main Contractor was faced with swamp like conditions in areas. The ground conditions were extremely silty and in weak areas, before geosynthethic material was used.
- **Solution Offered**: A combination of Geogrid and Geotextile was used to provide the required stabilized platform for this Road. An initial layer of Geogrid was used at the base to provide a rafting effect. Once the Road had been built up to formation level further layers of Geotextile and Geogrid were combined to stabilize the capping and sub base prior to the surfacing. Sermatech Nig Ltd successfully installed over 1000 rolls of Stratec G30PP Geogrid

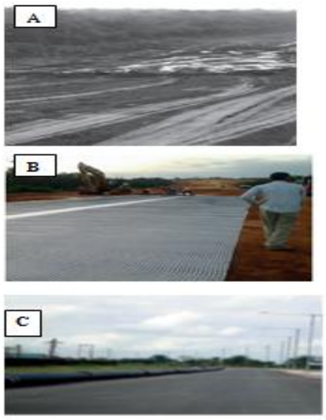

Figure 8: (A) Before, (B), During, (C), After layering of Geosynthetic material

II. LITERATURE REVIEW ON PRODUCTION, PROPERTIES, AND ENGINEERING APPLICATION OF GEOMEMBRANES.

A. Production

Geo-membranes are impermeable synthetic membrane liner or barrier used with any geotechnical engineering related material so as to control fluid (or gas) migration in a human-made project (landfill liners, sealing systems on embankment dams), structure, or system.
Geomembranes are made from relatively thin continuous polymeric sheets, but they can also be made from the impregnation of geotextile with asphalt, elastomer or polymer sprays, or as multilayered bitumen geocomposites. Continuous polymer sheet geomembranes are, by far, the most common (Rollin et al., 1991).

B. Types of Geomembrane

Figure 9: Geomembrane Types

The design and specification of geomembrane requires an understanding of the properties of the polymer used to manufacture the material. Polymer degrades with exposure to ultraviolet light, therefore carbon black and other additives are added to the polymer to enhance its resistance to degradation due to exposure to sunlight. Also a greater thickness increases the expected service life (Bureau of Reclamation, March 2014).

The common types of geomembrane are classified generally into two which are:

1. **Covered Geomembrane**: These are geomembranes only intended for covered application and when buried are predicted to last for 100 of years. One report cites a

service life in excess of 950 years. These geomembranes are predicted from the numerous elements that may damage exposed liners such as oxidation, abrasion, ultraviolet degradation, freeze, thaw, animal's intrusion, wind uplift and vandalization.

2. **Exposed Geomembranes**: Geomembranes that have been formulated for exposed application have a typical service for about 30years. However some geomembrane have been in operation for over 30 years on dam's faces with little or no loss in the original physical properties (Bureau of Reclamation, March 2014).

Table 1: General Geomembrane types and Polymers used

Geomembrane type	Abbreviation	Polymer type	Approximate resin formulation (Percent of total weight)	Comment
High-density polyethylene	HDPE	Thermoplastic	95–98	High resistance to UV and chemical degradation. Can be susceptible to stress cracking.
Linear low-density polyethylene	LLDPE	Thermoplastic	94–96	LLDPE has less resistance to UV and chemical degradation. Slightly more flexible than HDPE. Excellent elongation properties.
Polyvinyl chloride	PVC	Thermoplastic	30–40	Good flexibility at all temperatures. Could degrade quickly depending on plasticizer.
Chlorosulphonated polyethylene	CSPE	Thermoplastic rubber	40–60	Difficult to repair once installed because of vulcanization.
Ethylene propylene diene terpolymer	EPDM	Thermoset	25–30	Excellent flexibility. Seams must be glued and may not be as durable as other membranes.
Polypropylene (flexible)	fPP	Thermoplastic	85–96	Fairly new product and service life not well known, but considered to be flexible and easy to install.

C. Properties of Geomembrane

The majority of generic geomembrane test methods that are referenced worldwide are by the ASTM International (American Society of Testing and Materials - ASTM) due to their long history in this activity.

1. **Physical properties:** The main physical properties of geomembranes in the as-manufactured state are: Thickness (smooth sheet, textured, asperity height), Density, Melt flow index, Mass per unit area (weight), Vapor transmission (water and solvent) (Bureau of Reclamation, March 2014).
2. **Mechanical properties:** Numbers of mechanical tests that have been developed to determine the strength of polymeric sheet materials; Tensile strength and elongation (index, wide width, axisymmetric, and seams), Tear resistance, Impact resistance, Puncture resistance, Interface shear strength, Anchorage strength, Stress cracking (constant load and single point) (Bureau of Reclamation, March 2014).
3. **Endurance Properties:** Any phenomenon that causes polymeric chain scission, bond breaking, additive depletion, or extraction within the geomembrane must be considered as compromising to its long-term performance. Obviously, many of the physical and mechanical properties could be used to monitor the polymeric degradation process; Ultraviolet light exposure (laboratory of field), radioactive degradation, Biological degradation, Chemical degradation, Thermal behavior, Oxidative degradation (Bureau of Reclamation, March 2014).

D. Engineering Applications of Geomembrane

Geomembranes have been used in the following environmental, geotechnical, hydraulic, transportation, and private development applications:

1. **Landfill**: The primary purpose of a Daelim Geomembrane liner in a landfill is to protect the groundwater from being contaminated. Daelim HDPE Geomembranes are resistant to most wastes and exceed the requirements of impermeability. Hazardous waste landfills require double-liners and leachate collection / removal systems. Sanitary landfills may require a single liner with a leachate collection / removal system.

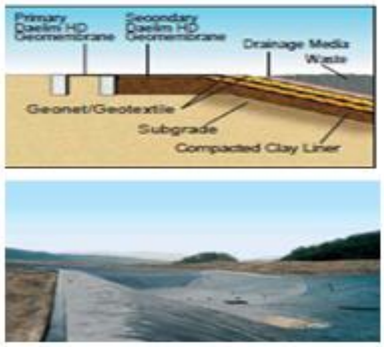

Figure 10: Geomembrane used for Landfill (Geosynthetic material association, January 2010)

2. **Cap and Closure**: Daelim HDPE Geomembranes are used in landfill caps to prevent fluid flow into the landfill, thereby reducing or eliminating the generation of waste liquid after filling the landfill. The cap is also designed to trap and properly vent the gases generated during decomposition of organic waste. Another advantage is that the completed cap allows for efficient revegetation and restoration of the land. In addition, it may be possible to expand the landfill vertically, thereby enlarging the landfill capacity.

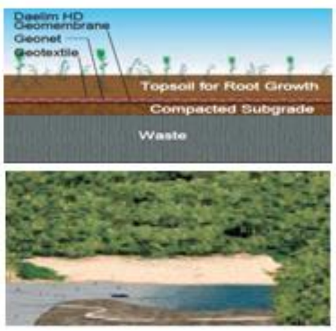

Figure 11: Geomembrane used as Cap and Closure (Geosynthetic material association, January 2010)

3. **Pond Liners**: The Clean Water Act has required most publicly operated waste water treatment plants to install lagoon liner systems to prevent contaminants from entering groundwater sources or streams. In addition, the use of Daelim Geomembrane liners in potable water reservoirs conserves millions of ton of water annually by preventing

seepage loss. Pond liners can also be used in applications such as golf courses, amusement parks, resorts, agriculture and aquaculture.

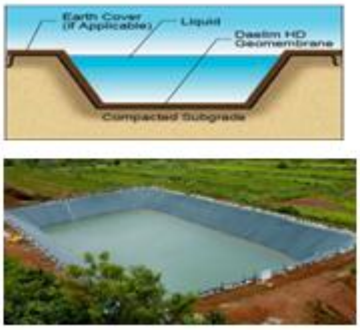

Figure 12: Geomembrane used for Pond Liners (Geosynthetic material association January 2010)

4. **Mining**: The use of Daelim HDPE Geomembrane may result in more productive mining. New processes involving the heap leach method of precious metal extraction using chemical solutions have resulted in low cost extraction from low grade ores. The use of flexible Daelim Geomembrane liners prevents the contamination of the soil and groundwater by these chemical solutions.

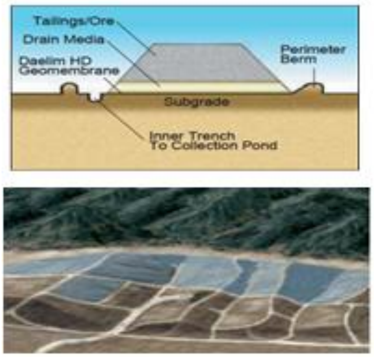

Figure 13: Geomembrane used for Mining (Geosynthetic material association January 2010)

5. **Secondary Containment**: Tank farms are lined to prevent groundwater contamination in the event of a chemical spill. The secondary containment system can be placed on concrete or directly on the ground. These liner systems for secondary containment can be very sophisticated utilizing elaborate attachments to tank and other structure. In other cases, geomembranes protect simple earthen impoundments and dikes.

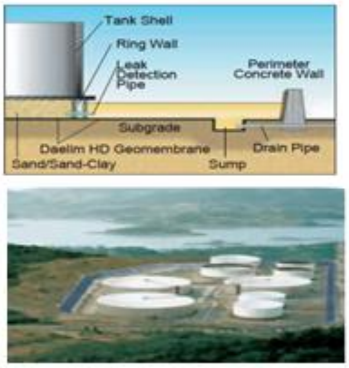

Figure 14: Geomembrane used in Secondary Containment (Geosynthetic material association, January 2010)

6. **Canal Liners**: Daelim HDPE Geomembranes are viable alternatives to concrete and compacted earth for lining canals to reduce seepage. Daelim HDPE Geomembrane can be used as an expedient method to repair existing deteriorated concrete linings.

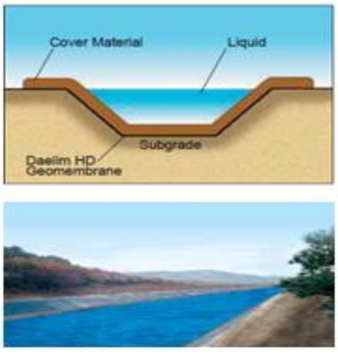

Figure 15: Geomembrane used for Canal lining (Geosynthetic material association, January 2010)

E. CASE HISTORY: JIBIYA DAM (1987) GADA RIVER, KATSINA STATE

- **Main Contractor**: Semebenelli Consulting srl Italy
- **Location/Project**: Jibiya dam 1987, Gada River, Katsina State, Nigeria.
- **Project Characteristics**

a. **Works**: Earth fill dam, spillway, and in take tower, valve chamber
b. **Purpose**: irrigation and water supply

- **Dimension:**

a. Height: 23.5m
b. Embankment Volume: 2,000,000m^3
c. Storage: 142,300,000m^3
d. Crest Length: 3600m
e. Geomembrane Liner: 165,000m^3
f. Spill way Capacity: 2100m^3/s

- **Water Lightness:** PVC Geomembrane plus pp geotextile geocomposite on the upstream slope vertical plastic diaphragm at the upstream toe.
- **Material Used:**

a. **Foundation**: Eolic sand, Riverbed sand, Gneiss, Diorite.

b. **Embankment**: Eolic sand.

- **Professional Service Offered**: The upstream slope is set at 3H/1V and lined with a continuous geosynthetic liner tied to the top of a vertical, plastic diaphragm wall reaching into foundation rock. The diaphragm wall stops short of the dam's ends where it is replaced by a horizontal geomembrane blanket.

Figure 16: (A): side view geosynthetic liner, (B): upstream view of dam, (C): Dam completion

IV. ADVANTAGE AND PROBLEMS ASSOCIATED WITH THE PRODUCTION/ USES OF GEOSYNTHETICS

A. Advantages

- The manufactured quality control of geosynthetics in a controlled factory environment is a great advantage over outdoor soil and rock construction. Most factories are ISO 9000 certified and have their own in-house quality programs as well (Sarsby, R. W. Ed. 2007).
- The low thickness of geosynthetics, as compared to their natural soil counterparts, is an advantage insofar as light weight on the subgrade, less airspace used, and avoidance of quarried sand, gravel, and clay soil materials (Sarsby, R. W. Ed. 2007).
- The ease of geosynthetic installation is significant in comparison to thick soil layers (sands, gravels, or clays) requiring large earthmoving equipment (Sarsby, R. W. Ed. 2007).
- Published standards (test methods, guides, and specifications) are well advanced in standards-setting organizations like ISO, ASTM, and GSI (Sarsby, R. W. Ed. 2007).
- Design methods are currently available from many publication sources as well as universities which teach stand-alone courses in geosynthetics or have integrated geosynthetics in traditional geotechnical, geoenvironmental, and hydraulic engineering courses (Sarsby, R. W. Ed. 2007).
- When comparing geosynthetic designs to alternative natural soil designs there are usually cost advantages and invariably sustainability (lower CO_2 footprint) advantages (Sarsby, R. W. Ed. 2007).

B. Problems associated with Production/ Uses of Geosynthetics

- Long-term performance of the particular formulated resin being used to make the geosynthetic must be assured by using proper additives including antioxidants, ultraviolet screeners, and fillers (Sarsby, R. W. Ed. 2007).
- The exposed lifetime of geosynthetics, being polymeric, is less than unexposed as when they are soil backfilled (Sarsby, R. W. Ed. 2007).
- Clogging or bioclogging of geotextiles, geonets, geopipe and/or geocomposites is a challenging design for certain soil types or unusual situations. For example, loess soils, fine cohesionless silts, highly turbid liquids, and microorganism laden liquids (farm runoff) are troublesome and generally require specialized testing evaluations (Sarsby, R. W. Ed. 2007).
- Handling, storage, and installation must be assured by careful quality control and quality assurance (Sarsby, R. W. Ed. 2007).

V. RECOMMENDATION AND CONCLUSION

A. Conclusions

Geosynthetics have been utilized in numerous civil and environmental engineering applications worldwide for more than 20 years to prevent seepage of liquids. Such seepage control applications as water containment and conveyance, structure waterproofing, and environmental protection make extensive use of geomembranes, geotextiles, geosynthetic clay liners (GCLs) along with other geosynthetics.

The wide variety of potential exposure conditions is why there is such a wide variety of geosynthetic barrier materials. Material selection and installation details are, therefore, project specific most especially in geotechnical and engineering applications.

B. Recommendations

Geotextiles are more effective than traditional products like concrete, asphalt & clay capping due to their wide range of physical, mechanical and chemical resistance properties protecting our environment and water resources.

Government should encourage and imbibe the use of Geosynthetics for Engineering/ Geotechnical Construction purpose.

With much emphasis and studies, it is quite economical to introduce the use of geosynthetics as a whole into the Engineering industry. The materials involved is very effective in separation of subgrade and sub-base courses in road construction and other engineering constructions

REFERENCES

ASTM (1994). Standards and Other Specifications and Test Methods on the Quality Assurance of Landfill Liner Systems. ASTM, 1916 Race Street, Philadelphia, PA. April.

Abdullah, A. B. M., (2000). A Handbook of Geotextiles Particularly natural Geotextiles from jute and other vegetable fibers, FAO- ASTM (1994), Annual Books of ASTM Standards, American Society Testing and Materials, Philadelphia, Pennsylvania. Volume 4.08 (1), Soil and Rock, Volume 4. No. (8), Soil and Rock, Geosynthetics, Volume 7, No. 1, Textiles.

Agrawal, B. J. (2011). Geotextile: Its application to civil Engineering, overview. National Conference on Recent Trends in Engineering & Technology

Andrawes, K. Z., McGowan, A., Wilson-Fahmy, R. F., and Mashhour, M. M., (1982). "The Finite Element Method of Analysis Applied to Soil-Geotextile Systems," Proceedings of the 2nd international Conference on Geotextiles, Las Vegas, Aug l-6, Vol. 3, pp. 695-700,.

Bureau of Reclamation, (March 2014). Design Standard No. 13, Embankment Dams, Chapter 20- Managing water in the West.

Dauda, J. and Salami, B. (2012). "An investigation into the physical properties of landfill liners". Unpublished B. Tech Project Report, Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria, pp 56-59,

Dixon, N., Smith, D. M., Greenwood, J. R. and Jones, D. R. V. (2003). Geosynthetics: Protecting the Environment, Thomas Telford Publ., London, England.

Geosynthetic Materials Association (GMA). (2010). Application of Geomembranes, United State of America

Holtz, R. D., Christopher, B. R. and Berg, R. R. (1997). Geosynthetic Engineering, BiTech Publishers, Ltd., Richmond, B.C., Canada.

Jewell, R. A. (1996). Soil Reinforcement with Geotextiles, CIRIA Publishers, London, England.

Kercher, A. (2011) .Geosynthetics Application. Kercher Engineering, Inc. Retrieved May 25, 2011, from.http://www.kercherei.com/pw_institute/geosynthetics/geo.html.

Paul Guyer, J. (2009).An introduction to geotextiles in drainage and pavement applications.

Pilarczyk, K. W. (2000). Geosynthetics and Geosystems in Hydraulic and Coastal Engineering, A. A. Balkema Publ., Rotterdam, the Netherlands.

Rankilor, P. R., (1981). Membranes in Ground Engineering, John Wiley and Sons, New York,

Rollin, A., Rigo, J. M. (1991). Geomembranes: Identification and Performance Testing, Chapman and Hall Publ., London, 355 pgs.

Rowe, R. K. (Ed.), (2001). Geotechnical and Geoenvironmental Engineering Handbook, Kluwer Academic Publishers, Boston, US.

Shukla, S. K. and Yin, J.-H. (2006). Fundamentals of Geosynthetic Engineering, Taylor and Francis Publishers, London, England.

Sarsby, R. W. Ed. (2007). Geosynthetics in Civil Engineering, Woodhead Publishing Ltd., Cambridge, England.

STRATEC GEOSOLUTIONS (2013). Margaret Ekpo International Airport Bypass, Nigeria.

Tripti, B., Shahnaz, J. (2012). Engineering uses of textiles in Geotextile. published in the Textile Review magazine

Wikipedia (2011). Geosynthetics, Retrieved May 25, 2011, from http://en.wikipedia.org/wiki/Geosynthetic

Wesseloo, J. O., Visser, A. T and Rust E. H. (2004). "A Mathematical Model for the Strain Rate Dependent Stress-Strain Response of HDPE Geomembranes". Geotextiles and Geomembranes 22, No.7: 273-295.