11th Int. Conf. on Geotechnique, Construction Materials & Environment, Kyoto, Japan, 3-5 November 2021, ISBN: 978-4-909106063 C3051

THE ISO DESIGN GUIDE FOR GEOSYNTHETIC BARRIERS AND THE USE FOR SAFE AND ECONOMIC BARRIER SOLUTIONS

Kent von Maubeuge[1] and Jake Stoyle[2]

[1]NAUE GmbH & Co. KG, Germany; [2]NAUE Geosynthetics Ltd., UK

ABSTRACT

Over the past 40 years, the advantages in utilising geosynthetic barriers versus traditional barrier materials have been well documented, e.g., greater project economy, extended service lives, enhanced environmental protection, and greater site safety. Achievements such as conserving water resources and enabling beneficial site reuse have even given geosynthetic engineering a level of importance. As such, the use of geosynthetic barriers has increasingly been required. However, there are regions and applications in which the use of these barrier technologies should be more widely adopted. This paper highlights the principles and practices of design using geosynthetic barriers and takes into account a number of different parameters. An ISO design guide aims to assist the process by identifying the various characteristics of barrier types and comparing them with the requirements of a variety of different applications. It also offers design advice to professionals involved in the design of civil engineering and construction solutions using geosynthetic materials. Overall, the intent is to encourage appropriate selection of materials and design methods to suit particular applications, rather than to redesign projects to suit predetermined materials. This paper will describe both the process and outcomes of a new ISO design guide for barrier systems, some of the challenges and make recommendations how it can be used to improve regulations. Further, an example of successful use of barrier systems for encapsulation of debris from Fukushima with an innovative barrier system is described.

Keywords: Geosynthetic clay liner, Barrier, Multicomponent, Guideline, Liner

INTRODUCTION

Geosynthetic barriers are an established product group in the geo-environmental industry. They include factory-made polymeric geomembranes (e.g., HDPE), bituminous barriers (bitumen attached to geotextile), and geosynthetic clay liners (with clay/bentonite core). These geosynthetic materials are accepted as barrier solutions for landfill caps and base liners, under roadways and railways, and with various containment structures such as dams, canals, ponds, rivers, and lakes. They are also used for waterproofing of buildings and similar structures. Advantages of geosynthetic barrier systems vs. traditional designs include:

- More economical to produce, transport, and install (quicker and simpler)
- Enable predictability designs
- Reduced excavation required (e.g., less fill required, less land disturbed)
- Clear, established quality controls from production through installation
- More homogeneous than soil and aggregates
- Less environmentally sensitive and lower environmental impact
- Improved performance and durability
- Better sustainability
- Better resilience

The use of geosynthetic barriers continues to grow internationally, but more regulatory support is needed and also a better understanding of the limitations when designing with these types of geosynthetic barriers as a wrong design can cause a risk to the design without the geosynthetic being the pulling trigger.

BRIEF HISTORY OF GEOSYNTHETIC BARRIER SYSTEMS

Geomembranes (ASTM D4439 [1] definition: an essentially impermeable geosynthetic composed of one or more synthetic sheets) can be either smooth or textured on the surface, are essentially impermeable and are used as fluid barriers. Textured surfaces provide an enhancement of frictional characteristics, which allows designs on steeper slopes or where shear stress occurs. Geomembrane liner materials belong to the group of geosynthetic polymeric barriers (GBR-P) and the terminology of these types of products are defined by ISO 10318 [2] as follows: Factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is fulfilled by polymers other than bitumen.

Geosynthetic clay liners (GCL) (according to ASTM 4439: a manufactured hydraulic barrier consisting of clay bonded to a layer or layers of geosynthetic materials) also known as geosynthetic clay barrier (GBR-C) according to ISO 10318 [2] are:

Factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is fulfilled by clay.

Most recently, multicomponent GCLs (Fig. 1) are introduced to the market and enable to challenge particular site conditions (prevent desiccation, perform against critical chemical fluids, reduce root penetration, under extreme hydraulic gradients, etc.) where the use of GCLs has previously been limited. The following definition proposals are currently being used in ASTM D35 standards: multicomponent GCL, a GCL with an attached film, coating, or membrane decreasing the hydraulic conductivity or protecting the clay core or both.

BARRIER APPLICATIONS

With the increasing number of geosynthetic barriers and the increasing potential of barrier applications, geosynthetic barrier systems are becoming a very important part of the construction industry. Geosynthetic barriers provide a number of benefits and it is these benefits that are attracting more clients and construction professionals to their use. Geosynthetic barriers can often reduce the amount of excavation and fill material. They also provide a number of design benefits both technical and aesthetic. These benefits can have an effect on the cost of a project, and many solutions using geosynthetic barriers as opposed to more traditional methods have resulted in reduced costs. In addition to cost, sustainability of a construction solution is also very important. Hopefully with government targets and legislation, designers, owners, operators and manufacturers are being driven towards reducing their carbon footprint and carbon emissions (Fig. 2). And besides the design benefits provided by geosynthetic barriers, they have also been shown to reduce the carbon footprint of a number of construction projects [3]. Geosynthetic barriers are widely used in all types of applications where liquid or fluid tightness is required to prevent any kind of inflow or outflow. In the following the most known applications are described.

Fig. 1 Multicomponent geosynthetic clay liner – attaching an extruded polymer coating to the GCL

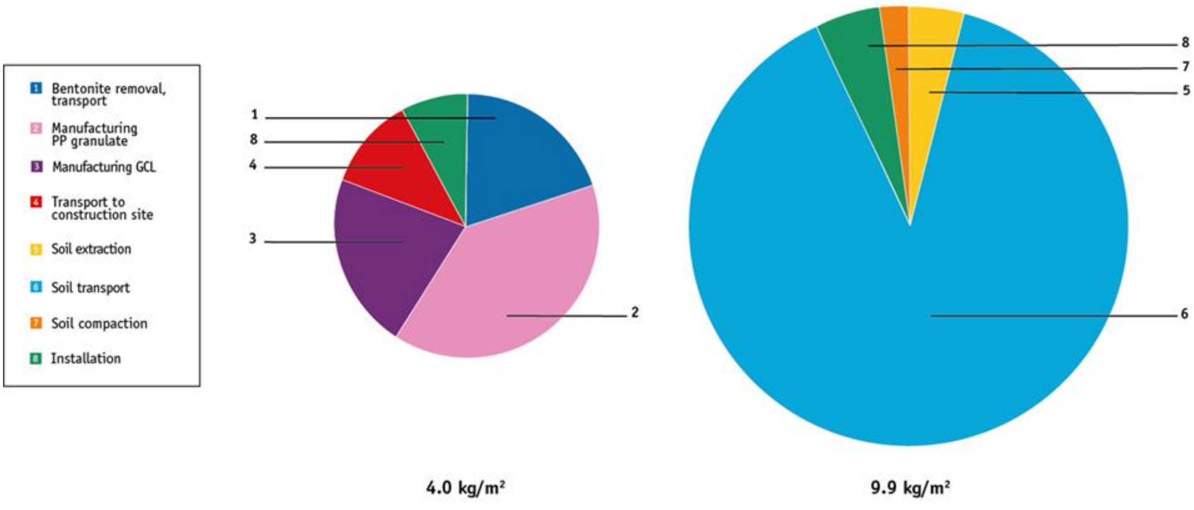

Fig. 2 Comparison of CO_2 emissions of a GCL (left) and a compacted clay liner (right) in a 36,000 m² large landfill cap [3]

Landfill Barrier Systems

Many modern landfills constructed over the past decades are performing very well and this is due to the fact that the content of landfills is considered hazardous for the environment and that landfills are typically located in cities or at least nearby to them, so that the effect on the environment is noticeably in an early stage.

Further regulations have been developed in the last decades, ensuring proper design and proper requirements to ensure that the geosynthetic barrier system in the base or as a cap will last far beyond the estimated design life of the landfill structure. There are several factors which contribute to the protection of the environment, but one key factor is the use of a polymeric geomembrane and/or a geosynthetic clay liner (GCL).

Surface Impoundments

Numerous national regulatory bodies have passed wide-reaching clean water legislation. Many of these regulations require the use of geomembrane liner systems in treatment lagoons at publicly operated wastewater treatment plants. These are also being used in potable water reservoirs (e.g., liners and floating covers). Here, these materials and systems have helped conserve water annually by minimising water seepage.

Also, storm water retention and detention management increasingly require smart lining solutions and include geomembranes, geosynthetic clay liners (GCLs) and multicomponent lining systems.

Geosynthetic products can also be used for practical or decorative pond liners at golf courses, amusement parks, and resorts, as well as in agriculture and aquaculture to create healthier, more efficient, and cost-effective systems.

Mining Applications

The daily mining rates, scale of single-site operations, and costs associated with mining increase every year. Advances in extraction technologies have greatly increased recovery rates from ore bodies. Geomembranes and GCLs under the large leach pads prevent the loss of valuable metal-laden chemical solutions while protecting soils and groundwater.

Geosynthetic barriers are also used to recapture and recycle harmful chemicals on site and in secondary containment applications.

Geosynthetics can aid in channelling surface water run-off and in preventing rainwater intrusion into heap leach pads, thus minimising solution dilution. In general, few regulations govern mining usage of geosynthetic barriers. Basic environmental laws apply, country by country; but the mining industry is unique in that it increasingly adopts geosynthetic barriers primarily for economic advantages.

Environmental Protection in Infrastructure Applications

Groundwater protection is generally required where a road enters a groundwater sensitive area, to avoid damage from winter maintenance with de-icing salt, everyday pollution arising from motor vehicles, and to protect the area from accidents with the possible release of polluting substances [4]. This German Guideline of the RiStWag [5] was one of the earlier guidelines on this topic (first publication 1982). The guideline describes, among other things, geomembranes and GCLs for environmental protection (Fig. 3).

Encapsulation of Contaminated Soils

Road noise and view-blocking barriers along roads and railway lines can be built with lightly contaminated soils or recycling material [6]. This may include slag, ash, contaminated soils from remediated sites, and residue from construction waste recycling or industrial processing. These wastes must meet certain environmental-chemical requirements and must be provided with a surface sealing cap (Fig. 4) to prevent water penetration and any contaminant transport. Suitable sealing materials for these purposes include GCLs and geomembranes.

Water Conveyance in Canals

Government agencies such as the United States Bureau of Reclamation (BuRec) indicate that seepage from unlined irrigation canals and waterways may be substantial and costly; and that geosynthetic barriers offer economically flexible and highly effective performance enhancement for canals. They are effective alternatives to concrete, asphalt or compacted clay soils. Stark and Hynes [7] summarised numerous geosynthetic barrier installations in canal systems, including single geomembranes (various polymers), exposed and buried installations, and composite systems, such as geomembrane with geotextile protection or concrete cover.

In Germany, all important technical information on waterway lining systems has been collated in the new guideline, “Recommendations for the use of lining systems on beds and banks of waterways.” The guideline, taking into account local boundary conditions, provides liner system selection information to be used by agencies. The focus is primarily on the underwater installation of GCL.

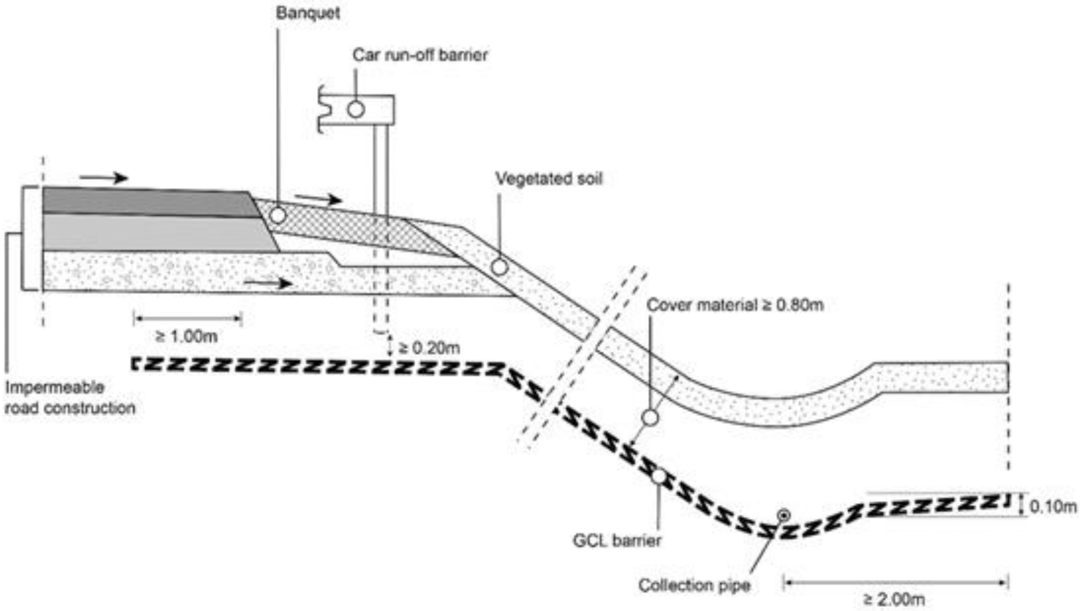

Fig. 3 Groundwater protection for a road dam construction [according to 5]

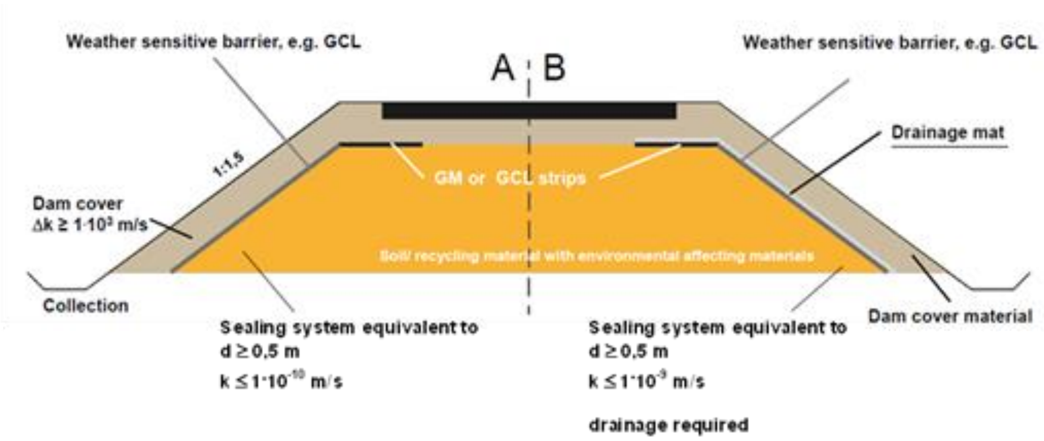

Fig. 4 Typical cross section of geosynthetic barrier system for the encapsulation of contaminated soils in road constructions

Dams – Levees – Dykes

Geosynthetic barriers provide easy-to-implement solutions for dams and flood defences, with project records extending back 40 years or more. When waters rise in a levee system, the integrity of the levee itself may be at risk. If water permeates the earthen structure, it weakens the dam stability and precipitates failure. Geosynthetic barriers resolve threats like this, often in ways that can be adapted easily to the local conditions. For flood protection and dam designs (Fig. 5), geosynthetic barriers (geomembranes and GCLs) provide long-term sealing performance, prevent permeation through the earthen construction and may reduce the dam or levee stability.

Fig. 5 Geosynthetic clay liner as hydraulic barrier in a water storage dam

Coal Ash Storage

In recent years, there have been several tragic failures of coal ash storage facilities worldwide and in many documented cases groundwater contamination at or nearby coal ash storage facilities. This contributed to the US EPA's issuance of new regulations for the storage of coal ash which require the use of geosynthetic materials. The US EPA regulations for coal ash storage propose the most efficient and effective barrier system as a composite liner system using a primary geomembrane (GM) liner, in combination with a compacted clay liner (CCL), approx. 500mm thick, or a needle-punched geosynthetic clay liner (GCL).

THE ISO DESIGN GUIDE

This new design guide ISO/DTR 18228-9 [8] is intended to offer advice to designers as to what to consider when using geosynthetics in a particular civil engineering or construction design [9]. As such it needs to cover a range of applications, material types, climatic and geological issues. Further, it covers installation and site preparation / completion recommendations. The emphasis is on choosing the most appropriate type(s) of material(s) for the application rather than changing the design to suit a particular material.

A possible whole process (Fig. 6) is organised into a basic flow chart to guide designers through the process of choices which need to be considered when designing with a geosynthetics barrier and the possible actions are described below.

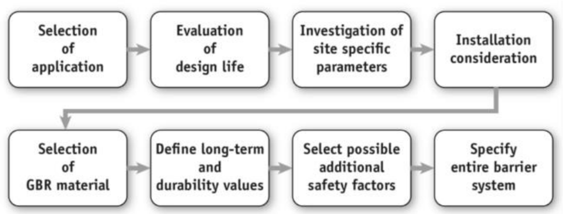

Fig. 6 Organised basic flow chart for designers when considering a geosynthetic barrier

- Selection of application: The first part of the process asks to select the application. With that it is necessary to check local regulations and requirements.
- Evaluation of design life: During this evaluation process, it is necessary to find out what the life time expectations should be, knowing that no construction method lasts forever. Realistically, they can be 5 (e.g., temporary solutions), 25 (e.g., secondary containment), 50 (e.g., containment non-landfills) or 100 years (e.g., landfills).
- Investigation of site-specific parameters: This is a very important part, as all site-specific conditions need to be evaluated and they have influence on the performance of the barrier system. It includes soil types on site, inclinations, weather conditions, vegetation, burrowing animals, etc.
- Installation considerations: Geosynthetic barrier systems are likely to be less sensitive to installation than traditional barrier systems like compacted clay liners, but they are still considered as relatively thin elements. Therefore, the installation process as well as the surrounding soil types need to be considered as well.
- Selection of barrier system: Balancing the combination of often conflicting performance criteria and different GBR materials to the proposed installation is always a complex matter. This inevitably comes down to professional judgement which geosynthetic barrier system suits best for the selected application.
- Define long-term and durability values: For a few applications there are well federal regulated geosynthetic barrier requirements. This process ensures national consistency and minimum standards while providing flexibility to states in implementing rules. It should be noted that the baseline of known requirements is pretty strict in material properties (e.g., GRI-GCL-3 [10] and GM-13[11]) and design selections are also sometimes available (e.g., GRI-GCL5 [12]).
- Select possible additional safety factors: Areas such as subgrade preparation, slope stability, climatic conditions, protection and hydraulic uplift, installation parameters and types of CQA are also considered as to what effect these may have on the design as well as what additional factors of safety they may offer.
- Specify entire barrier system: Obviously, a well prepared and written complete specification will avoid issues and questions on site.

One topic which the standard does not address is costs, not because these are not important but they can vary enormously according to the availability of types of materials, transport distances and costs, installation expertise etc. Good quality design needs to consider the cost effectiveness of any solution but must first qualify and meet all technical and service expectations of the stakeholders in the end use.

Additionally, as not mentioned yet, a good quality control and assurance plan from the manufacturing to the installation is also required. One set of good guide specifications and quality control on the manufacturing side is documented in the GSI specifications and they have seen worldwide implementation and use. The test methods include ASTM and ISO standards and have harmonised ASTM and ISO tables. The specifications are under constant review and are updated frequently (http://geosynthetic-institute.org/specs.htm).

GEOSYNTHETICS NEED TO BE INCLUDED IN REGULATIONS

There is every reason to believe that geosynthetics will continue to be adopted into regulations around the world. No other field of engineered materials has developed as rapidly or gained such wide-spread acceptance as geosynthetics. This has much to do with the innovation and quality control measures in manufacturing and care of handling in the field. It also has much to do with geosynthetics being used in two primary situations: to perform better and/or more economically than traditional geotechnical designs. With a large record of data in support of cost and performance measures, and with secondary benefits such as decreased project carbon footprints with geosynthetics, the field's growth is assured.

It is absolutely necessary that regulations include application accepted geosynthetics in their regulations to allow cost-effective and high-performing solutions as they are already state-of-the-art and state-of-practice.

ISO DESIGN GUIDE AS THE BASIS FOR REGULATIONS

In many parts of the world, landfills are very well regulated by the federal government agencies through the process known as rulemaking. Such processes should also be introduced in other application regulations to ensure national consistency and minimum standards while providing flexibility to states in implementing rules. In general, following the approach of the ISO design guide is a good start what the expectations are.

Designers, authorities or other involved parties should recognize that geosynthetics cannot be specified purely on properties. It is important to see the big picture and consider all facts of the project, such as the German RiStWag guideline indicates in Fig. 7.

CASE STUDY: FUKUSHIMA NUCLEAR WASTE STORAGE

In March 2011, the Fukushima Nuclear Power Plant was severely damaged by an earthquake and tsunami. The subsequent radioactive leakage at the site led to the event being classified as a Level 7 on the International Nuclear Event Scale (INES). To date, the only other disaster to equal this radioactive threat to a population was the 1986 Chernobyl disaster. The epicentre of the earthquake was 72 km from the area in the Pacific Ocean. At 9.0 – 9.1, it ranks as the most powerful earthquake ever recorded in Japan. The tsunami waves produced by the quake were up to 40 m high.

The waves that reached the Fukushima Nuclear Power Plant were roughly 14 m high, which allowed them to overtop the seawall around the plant. Four reactors were flooded and the emergency generators failed, shutting off the coolant circulation pumps. With the cores not being cooled, the plant experienced nuclear meltdowns and hydrogen explosions in three of the four reactors that had suffered flooding. Radiation was released over a series of days. More than 154,000 people were evacuated from the area.

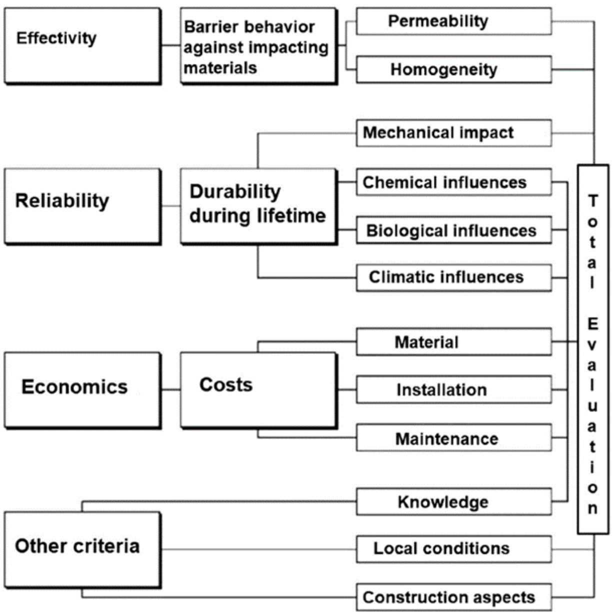

Fig. 7 Additional aspects for barrier systems requested by the German RiStWag guideline for groundwater protection in infrastructure projects [5]

In the years since the disaster, engineers have worked to design temporary and final disposal sites for the contaminated soils and waste from Fukushima. Geosynthetic containment has been a key part of the Interim Storage Facility (ISF) plan to enable waste to be stored without negatively impacting the soils beneath the ISF itself.

The primary ISF, which is in operation, will ultimately house 14.1 million m³ of contaminated material until a final disposal site is finalised. The contaminated material arrives at the initial soil separation facility in flexible bulk bags. A series of conveyor belts feeds the bag through a bag opener, sieving machine, soil improvement, removal of bag waste, a secondary sieving machine, removal of plant-based material, and finally the separated soil piles that are ready for interim storage.

In the soil storage area, the separated soil is deposited from trucks onto covered conveyor belts that deposit the waste in the lined disposal cell. A leachate collection system controls seepage and transports any leachate to a special treatment facility. Due to the importance of the barrier function, the ISF disposal cell is lined with a geosynthetic clay liner (GCL). Approximately 20,000 m² of a multicomponent GCL material was supplied in March 2018 (Fig. 8).

This particular GCL is one of the newer types within this barrier class. It is a multicomponent GCL that utilises an extruded, polyethylene coating on one side to enhance the material's performance against risks of desiccation, cation exchange, gas emission, and bentonite erosion. The special coating ensures that the GCL's ability to perform its impermeable barrier function is optimised. For a highly sensitive waste disposal site requiring long-term containment, it is a strong design strategy. The ISF is expected to receive all planned soils and waste by the end of 2021.

The ISF project is not the first use of geosynthetic clay liners in the management of contaminated soils from the disaster. In 2013, one of the early projects involved the installation of a GCL cap over contaminated soils. That project used a needle-punched GCL that has additional bentonite powder in the entire cover nonwoven to create self-sealing overlaps for a quicker, even more secure overlap sealing.

The use of GCL for lining the base and slopes of the contaminated soil storage facility and for capping contaminated soils to prevent the migration of polluted material emphasises how much trust engineers and environmental regulators have in these barrier systems.

Fig. 8 Installation of the PE extrusion-coated multicomponent geosynthetic clay liner

CONCLUSION

In many parts of the world governmental agencies have mandated the use of geosynthetics in many applications. The strongest sector seems to be landfills.

It is essential that their use is made mandatory in regulations in order to have efficient solutions with large potential on cost savings, safety of the designed structures and a minimum of environmental pollution including large reduction of the use of natural resources.

Most regulations describe material properties in detail or refer to existing specifications. However, some regulations show a shortage on other relevant design parameters, such as design issues, external effects, durability issues, installation considerations and/or quality control/assurance. The current version of the ISO design guide (approved and ready for publication) ISO/DTR 18228-9 "Design using geosynthetics — Part 9: Barriers" is an international standard containing recommendations and guidance for the design of geosynthetic barriers in geotechnical applications. It provides design guidance over various applications, design lives, material types, parameters and site-specific conditions. Obviously professional judgement is still needed in all designs and this guide will not substitute that as the document is intended only to assist in the process by identifying parameters which are relevant.

Good quality design needs to consider the cost effectiveness of any solution but must first qualify and meet all technical and service expectations of the stakeholders in the end use. All engineers must have a current working knowledge of the sort of costs incurred by their designs but the view was taken that to try and incorporate such parameters into the standards would be virtually impossible and almost certainly inaccurate.

REFERENCES

[1] ASTM D4439. Standard Terminology for Geosynthetics, ASTM International, West Conshohocken, PA, United States, 2020

[2] ISO 10318, Geosynthetics – Part 1: Terms and definitions, 2015

[3] Egloffstein, T. A., Heerten, G., von Maubeuge, K. P., Comparative life cycle assessment for clay geosynthetic barriers versus clay liners and other sealing systems used in river dykes, canals, storm water retention ponds and landfills. GBR-C 2K10; 3rd International Symposium Geo-synthetic Clay Liners, Germany, 2010

[4] von Maubeuge, K. P., and Post, A., Regulated groundwater protection in roads with geosynthetic barriers, Proceedings of the 17th African Regional Conference on Soil Mechanics and Geotechnical Engineering. 7, 8 & 9 October 2019 – Cape Town

[5] RiStWag FGSV Nr. 514, Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten (translated: Guidelines for Construction Projects in Waterways of Protected Areas), Forschungsgesellschaft für das Straßen- und Verkehrswesen, Germany, 2016

[6] MTSE FGSV-Nr. 559, Merkblatt über Bauweisen für technische Sicherungs-maßnahmen beim Einsatz von Böden und Baustoffen mit umweltrelevanten Inhalts-stoffen im Erdbau (Recommendation on construction methods for technical safety measures when using soils and building materials with environmentally relevant substances in earthworks). Forschungs-gesellschaft für das Straßen- und Verkehrs-wesen, Germany, 2017

[7] Stark, T.D. and Hynes, J.M., Geomembranes for Canal Lining. Proceedings of Geosynthetics 2009, Industrial Fabrics Association International, Roseville, Minn., USA

[8] ISO/DTR 18228-9, Design using geosynthetics — Part 9: Barriers, 2021

[9] von Maubeuge, K. P., Geosynthetic barriers in regulations and recommendations in line with the ISO design guide? Innovative Infrastructure Solutions, Springer Nature Switzerland AG 2018

[10] GRI-GCL3, Standard Specification for Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs), Geosynthetic Institute, Folsom, PA, USA, 2016

[11] GRI-GM13, Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes, Geosynthetic Institute, Folsom, Pennsylvania, USA, 2021

[12] GRI-GCL5, Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs). Geosynthetic Institute, Folsom, Pennsylvania, USA, 2013