The paper was published in the proceedings of the 17th African Regional Conference on Soil Mechanics and Geotechnical Engineering and was edited by Prof. Sw Jacobsz. The conference was held in Cape Town, South Africa, on October 07-09 2019.

Geosynthetic barriers in regulations and recommendations in line with the ISO design guide

K. von Maubeuge
NAUE GmbH & Co. KG, Espelkamp, Germany

ABSTRACT: Over the past 40 years, the advantages in utilizing 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 social importance. This is especially true in modern waste management cell design; a barrier application that has been so successful that it has influenced the design and specification of geosynthetics into mining, water and wastewater, and industrial applications. The principles and practices of design using geosynthetic barriers take into account a number of different parameters considered by professionals engaged in the process. A 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 geosynthetics 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. Many aspects of the design process have been considered as well as the particular parameters of various sites and applications.

1 INTRODUCTION

Geosynthetic barriers (GBR) are an established product group in the geo-environmental industry. They include factory-made polymeric geomembranes (e.g. HDPE) and geosynthetic clay liners, GCL, (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 are:

- Economical to produce, transport, and install
- Enable predictability designs
- Quicker, simpler installation
- 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
- Environmentally less sensitive and lower environmental impact
- Improved performance and durability

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.

2 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 these benefits 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. Hopefully, with government targets and legislation, designers, owners, operators and manufacturers are being driven towards reducing their carbon footprint and carbon emissions. 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 (Egloffstein 2010).

3 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. Regulatory bodies will continue to incorporate them. For barrier applications, this means geomembranes and GCLs. These geosynthetics offer a wide range of physical, mechanical and chemical resistance properties. Geomembranes can be compounded for greater resistance to ultraviolet light exposure, ozone and micro-organisms in the soil, while GCLs can be produced with various geotextiles for enhanced frictional properties. Different combinations of these properties exist in various geomembranes as well as GCL materials to address a wide spectrum of geotechnical applications and designs. Several methods are used to join or seam large panels of geomembranes and GCLs, in both factory-controlled and field environments. Each material has highly developed quality control techniques and unique characteristics that govern their manufacture and installation. As advanced products and manufacturing and installation techniques evolve, project economy and performance will continue to improve, both with and in wait of regulatory recognition.

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.

4 THE ISO DESIGN GUIDE ISO/TR 18228-9

To understand the process of how and why a client may decide between geosynthetic and 'traditional' methods in a design process, a designer would need to know that there are alternative solutions. Therefore, the person must have had pre-education on geosynthetics (best case), has heard verbally that geosynthetics can fulfil a function or has searched on his own and has found geosynthetics in the web. In the next stage the designer has to evaluate whether there are benefits of a geosynthetic to an extent where the clients change their minds about going with a 'traditional' method. Typically, the client bases his decision focused on costs. However, in some cases, authorities would bring up technical arguments, such as life time performance, installation issues, technical equivalency. But the governing factor is in many cases still the significant cost savings of a project by the employment of a geosynthetic method. Regardless the cost factor, the main focus of any designer is still the technical equivalency of the geosynthetic method versus the traditional method, when trying to convert to geosynthetic-based solutions.

However, material cost is the major factor in selection of most solutions, but there are still a number of cases where a geosynthetic solution may be less economical, yet provide other benefits. Reducing construction time is one of these benefits. Often in construction the aesthetics of the finished project are very important. Geosynthetics additionally allow the improving of the aesthetics of a project, e.g. vegetated retaining walls in comparison to a 'traditional' method (e.g. concrete wall).

The reason why geosynthetic newcomers are hesitant to use geosynthetics is the lack of experience of working with geosynthetics. Instead of using new technologies, designers and clients prefer to stick to known approaches, showing significant conservatism and lack of confidence in geosynthetic solutions, which unfortunately leads to geosynthetics not being specified and used as much as they could be.

For this reason, it was necessary for the geosynthetic industry to work closely with potential clients and designers in educating and removing their fears or concerns about geosynthetic solutions and one approach was to develop a suite of design guides for using geosynthetics. This project is currently being undertaken by ISO TC221, working group WG6, and is registered as an ISO technical report ISO/TR 18228-9:2018(E) "Design using geosynthetics - Part 9: Barriers".

These design guides are intended to offer advice to designers as to what to consider when using geosynthetics in a particular civil engineering or construction design. As such they need to cover a range of applications, materials types, climatic and geological issues, as well as covering likely expertise in installation and site preparation/completion in sometimes difficult to access sites. Geosynthetic barriers offer their own challenges to the designer with a plethora of different geosynthetics barrier types as well as materials, so any guide has to offer a combination of advice as to what might be most suitable as well as how to ensure that the chosen geosynthetics barrier type is able to perform as it is intended. 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.

4.1 *ISO design guide – applications*

The first part of the ISO document indicates what practices are followed in different parts of the world and lists the types of applications for geosynthetic barriers, GBR, (Fig. 1).

The various applications are described and allocated with a two/three letter acronym as follows:

- CA Containment application, non-landfill
- CC Chemical containment, non landfill
- CW Construction waterproofing
- LBL Landfill base lining
- LC Landfill caps
- SC Secondary containment
- TIA Transport infrastructure applications
- TU Tunnels
- WRS-e Water retaining structure, e.g. balancing ponds, dams, dykes and canals (usually empty)
- WRS-f Water retaining structure, e.g. reservoirs, canals (usually full)

Then the main characteristics of the barrier are tabulated against each application, with levels of importance given to each of the characteristics often considered for design purposes. These are of course subjective, but again are extracted from the experience and opinions of a number of experts.

A similar approach is taken solely for GCLs in the document GRI-GCL5 (2013).

Characteristic Parameter		CA	CC	CW	LBL	LC	SC	TIA	TU	WRS-e	WRS-f
Chemical resistance		2	1	3	1	2	1	1	2	3	3
Physical properties											
Hydraulic resistance	permeability	1	1	1	1	1	1	1	1	1	1
Mechanical property	tensile, puncture, tear strength	1	1	2	1	1	2	1	1	1	1
	uni- and multi-axial elongation	2	2	3	3	2	2	2	3	2	2
Abrasion resistance		4	4	4	4	4	4	4	4	2	2
Durability		50 yrs	25 yrs	50 yrs	100 yrs	50 yrs	25 yrs	25 yrs	100 yrs	25 yrs	25 yrs
Installation		1	1	1	1	1	1	1	1	1	1

1 - important 2 - project dependent requirement 3 – rarely required 4 not relevant

Figure 1. Main geosynthetic barrier characteristics tabulated against typical barrier applications

Barrier Type		CA	CC	CW	LBL	LC	SC	TIA	TU	WRS-e	WRS-f
GBR-P	HDPE	1	1	2	1	1	1	1	2	1	1
	LDPE	1	2	2	2	2	1	1	1	1	1
	PVC	3	4	3	4	3	4	3	2	2	1
	EPDM	3	4	3	4	3	4	3	3	1	1
	PP	3	3	3	4	2	3	2	3	2	2
GBR-C	Single-component	2	3	2	2	1	3	1	3	2	2
	Muli-component	2 (A)	2 (A)	2 (A)	2 (A)	1 (A)	2 (A)	1 (A)	2 (A)	2 (A)	2 (A)
GBR-B		3	3	2	4	3	3	2	2	2	2

1 – world-wide acceptance 2 – general acceptance 3 – rarely used 4 not recommended

(A) – compare with the relevant combined component

Figure 2. Acceptance of the main raw material types of geosynthetic barriers in typical barrier applications

4.2 *ISO design guide – material types*

Next, particular characteristics of the main types of geosynthetic barriers are considered. Figure 2 lists the main raw material types used and includes a brief explanation of their acceptance within a certain application. Once again, a table was developed using the application types against main types of geosynthetics barriers and considering their acceptance across the main world markets.

In the next step the ISO document considers the properties relevant to the design. This is a complicated part of the process as each property needs to be considered in the light of the material and service conditions. This area typically considers elements extraneous to the material, but considers the application parameters in which the material and design must work, so consideration is given to chemical and physical resistance, weathering and degradation, physical properties of the supportive substrate etc.

It is unusual for a "standard" that no answers or opinions (subjective or otherwise) are given to the user of the standard. The idea is to present a whole raft of issues (or questions) which should be asked or taken into consideration by the user of each of the parameters in their ultimate design combinations.

This is the main focus of the guide as it does not want to take away responsibility from the designer, but wants to give guide to unexperienced designer on the topic barrier systems.

The penultimate section covers the basic principles of design covering such areas as substrate preparation, stability, climate and temperate conditions quality control and jointing techniques and testing. Here parameters are discussed with opinions and recommendations offered. These are taken from an extensive review of recommendations made by materials manufacturers, industry experts and committee members. Again, 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.

5 ISO DESIGN GUIDE – WHOLE PROCESS AS FLOW CHART

Finally, this whole process (Fig. 3) 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.

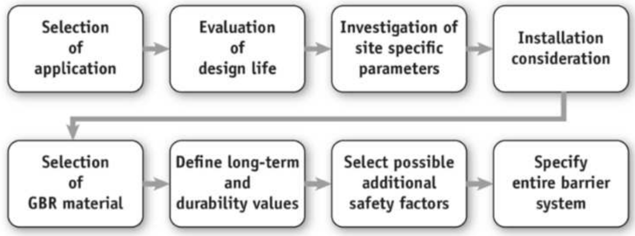

Figure 3. Organised basic flow chart for designers when considering a geosynthetic barrier (Atchison et al. 2016).

Any document prepared by a committee is fraught with the difficulties that multiple authors and views can expose. In order to satisfy the requirements of the ISO standards process, as well as having a satisfactory continuity and clarity of content, the chairs of the committee took time to explore carefully the scope and approach before putting substantial work into content.

One of the initial concerns, that perhaps the danger of producing a document that told engineers what to do, was considered in the ISO design guide document. Engineers and professionals are paid for their design input, expertise and experience. It was clear from the beginning that the document should offer advice, areas for consideration and show existing "common practice" based on years of experience in the sector. Any implication of "best practice" was to be avoided, as there are so many parameters to be considered that the combination of areas of consideration will be infinite and, as a result, the key to the document was to ensure that it identified "areas for consideration" as well as advice on the individual parameters for each.

One topic which the standard does not try to 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. 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.

Additionally, as not mentioned yet, a good quality control and assurance plan from the manufacturing to the installation is also required. One set of guide specifications and quality control on the manufacturing side is documented in the GSI specifications and they have seen worldwide implementation and use (Koerner 2010). The specifications are under constant review and are updated frequently (http://geosynthetic-institute.org/specs.htm).

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. The ISO document therefore cannot solve this potential conflict, but seeks to assist the designer in identifying and clarifying the various components of the decision-making process by identifying existing standards for comparisons of individual parameters and giving some direction on prioritization in various applications as well as conflicting performance characteristics which may be encountered.

6 HOW MUCH DO GUIDELINES REALLY REQUEST

In many parts of the world landfills are very well regulated by the federal government agencies through the process known as rulemaking. 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 (e.g. GRI-GCL3) and design selection (e.g. GRI-GCL5), but also allows more stringent requirements as well. In general, the requirements follow the approach the ISO design guide has set and describes very clearly what the expectations are. They typically cover all important aspects of a design and not only the geosynthetic material aspects.

Most federal landfill regulations additionally include the following details:

- Location restrictions - ensuring that landfills are built in suitable geological areas away from faults, wetlands, flood plains, or other restricted areas.
- Liner requirements – including geosynthetics, to protect groundwater and the underlying soil from leachate releases.
- Leachate collection and removal systems – to remove leachate from the landfill for treatment and disposal.
- Operating procedures
- Groundwater monitoring requirements
- Closure and post-closure care requirements – including covering landfills and providing long-term care of closed landfills.
- Corrective action procedures – control and clean up landfill releases and achieve groundwater protection standards.
- Financial assurance – provides funding for environmental protection during and after landfill closure (i.e., closure and post-closure care).

Not all regulation and recommendations go into the design that deep as we see it in landfill regulations, but it is noticeable that in the last years there is a great trend towards improvement. Designers, authorities or other involved parties recognized 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:

- Geosynthetic material properties
- Design issues (e.g. surrounding soil properties and materials, slope inclination, shear values, static and dynamic loads, groundwater, etc.);
- External effects (e.g. water head, confining stress, weather conditions, vegetation, climate, etc.);
- Durability issues (e.g. chemical, biological, UV, mechanical, etc.);
- Installation (e.g. geosynthetic protection, subgrade conditions, cover soil placement, overlapping/connection of geosynthetics, penetrations).

One example as how a new recommendation has considered nearly all topics of the big picture is the German RiStWag guideline (guidelines for construction projects in waterways of protected areas, 2016). The guideline describes, among other things, geosynthetic sealing systems for environmental protection caused by road traffic, especially in special declared areas over groundwater areas. Every German State and county have publicly available maps which show different zones around areas where drinking water is withdrawn from. Zones III are further away and zones I are directly around the pumping area.

The guideline considers the soil type and the permeability, the daily traffic volume and, based on the zone through which the road has to be constructed, the guideline recommends different type of road constructions, including the geosynthetic barrier system. It is very specific in the type of the road construction, including vehicle run-off barriers, cover soil thickness over the geosynthetic barrier, the rainwater collection system, fundamental geosynthetic properties, as well as maintenance during the lifetime of the road.

To allow site-specific considerations and new technology development, the guideline is very clear on other impacting factors and requests for designs to consider other aspects as well (Fig. 4).

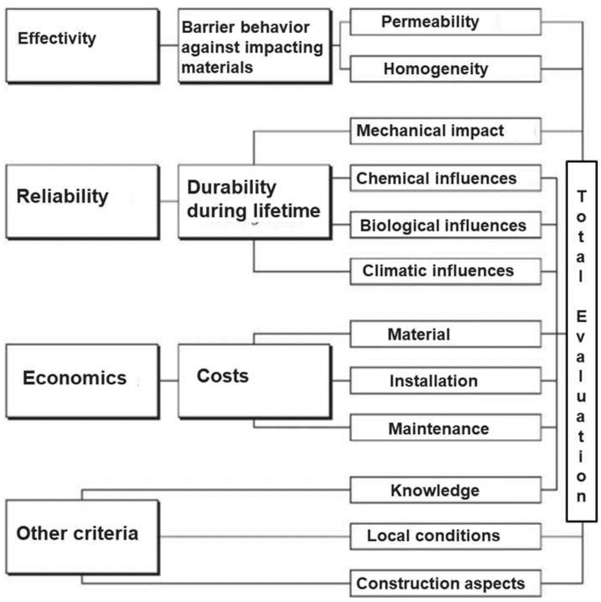

Figure 4. Additional aspects requested by the RiStWag guideline for barrier systems

7 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. In Europe, the Construction Products Directive (89/106/EEC; M/107) has to be followed. 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 currently drafted version of the ISO design guide “ISO/TR 18228-9:2018(E) “Design using geosynthetics - Part 9: Barriers” is, once published, 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.

8 REFERENCES

Atchison, P. & Von Maubeuge, K. 2016. Development of a design guide for geosynthetics barriers, as part of the ISO design using geosynthetics development. *EuroGeo6*.

Egloffstein, T. A. Heerten, G. & Von Maubeuge, K. 2010. 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 Geosynthetic Clay Liners, Germany*.

European Commission. M/107 Mandate to CEN and CENELEC concerning the execution of standardisation work for harmonised standards on geotextiles. Directorate-General III Industry; Industrial affairs II: Capital goods industries Construction

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

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

ISO/TR 18228-9:2018 (E). Design using geosynthetics – Part 9: Barriers.

Koerner, R.M. & Koerner, G.R. 2010. Generic specification for GCL manufacturing quality control; details and unsettled issues. GBR-C 2K10; *3rd International Symposium Geosynthetic Clay Liners, Germany*.

RiStWag 2016. FGSV Nr. 514. Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten (Guidelines for construction projects in waterways of protected areas). FGSV (Research Society for Road and Traffic), Germany.