Using geotextile filters in dam embankment construction

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ABSTRACT: Up to now geotextiles have been used successfully for nearly five decades for different purposes. In particular it is common practice to use geotextiles for filtration and drainage purposes in different kind of constructions like roads, levee dykes or similar structures. Despite this, geotextiles appear to be less used in dam embankment constructions. This study provides a short summary of the current practice of constructing dam embankments, which shows clearly the lack of regulations regarding using of geotextile filters in dam embankments. The design of filters and drains are also discussed in detail, including key aspects such as clogging, blinding, chemical stability, long-term durability and finally construction damages. Combining the above-mentioned aspects and based on the significantly increased knowledge in the design, testing and long-term behaviour of geotextile filters, positive experiences on different construction sides and the chance to save natural resources, it is the authors' opinion to rethink the use of geotextile filters in dam construction and further develop the current standards and guidelines.

1 INTRODUCTION

Geosynthetics in the form known today have been available for about five decades. It can therefore be safely stated that these products are no longer new to the construction industry. Furthermore, substantial effort has been made in conducting research into these materials, so that the mechanical properties and the interaction with the surrounding soil are well understood. This research is continuing and interesting observations and findings are still being made today (e.g. Derksen 2023).

- Geotextiles, amongst others, are one of the products which belong to the large family of geosynthetics and are mainly used for the following purposes: filtration.
- drainage.
- separation.
- protection.

Two of the purposes listed above, namely filtration and drainage, are linked to hydraulic engineering. Within this field, geotextiles are widely and successfully used for applications where filtration and drainage are required. Although this is the case for roads, levee dykes and similar structures (e.g. BAW 2021), the use of geotextiles appears to be less popular with dam engineers designing large embankment dams. Undoubtedly, quite a number of dams using geotextiles as filters and drains have been built, especially in South Africa. There are, however, only a few successful examples published in the literature where geotextiles have been implemented as filters (e.g. Giroud 2010).

This paper attempts to identify the reasons for this lack of published data and case studies, focusing on currently available guidelines and regulations, as well as experience gained during the past 40 years. Available methods for filter and drain design are not the focus of this paper and are only briefly discussed.

2 CURRENT PRACTICE AND CONCERNS

There are numerous national and international design guidelines and regulations regarding the construction of embankment dams, which can be large structures with a high risk to life and property in the case of a failure. A reputable and prestigious institution publishing internationally recognized guidelines and recommendations for embankment dams is the International Commission on Large Dams (ICOLD), which leads the profession in setting standards and guidelines to ensure that dams are built and operated safely, efficiently, economically, are environmentally sustainable, and socially equitable. In order to achieve this, at the core of the ICOLD activities, bulletins are published on various relevant topics. These bulletins can be considered "state of the art" documents and often become de facto national guidelines where these are not available or are referenced in national guidelines where they are available. To date, more than 180 bulletins have been published. Bulletin 55 (ICOLD 1986) specifically addresses the use of geotextiles as filters and transitions in fill dams but now dates back quite a number of years. The mindset at the time, was to consider using geotextiles as a filter only for secondary purposes and only where access, in case of a possible repair, was ensured. The application as a drain is not discussed at all in Bulletin 55. The bulletin was formulated based on data available 40 years ago, and the geosynthetic industry has innovated and advanced rapidly since then, opening the way for geosynthetic options to be considered as direct replacements for primary traditional granular filters.

Another regulation to mention in this regard is the German DIN (German Institute for Standardization) series 19700, parts 10 to 15 addressing various water retaining structures, from control reservoirs to large embankments. Most parts have been published in 2004 (e.g. DIN 2004a, b, c, d, e). Different construction materials are discussed in the DIN 19700 series but geotextiles are only mentioned in a small paragraph of part 10 of the series (DIN 2004a). Although DIN 19700 does not explicitly limit the use of geotextiles, it is also not of great help with regard to precise design information. The DIN 19700 series dates back to the early 2000s and is currently under review with an updated version that includes more guidance on the use of geotextiles expected to be published soon.

The lack of references in accepted design guidelines, or the possibly outdated knowledge about the behaviour of geotextiles in published guidelines, is certainly a major reason why geotextiles are still not routinely considered as a filter or drainage material in embankment dams. This is at odds with practice however, as there are successful and fully functional examples of embankment dams incorporating geotextile filters.

Considering the fact that the construction process can be significantly accelerated by the use of geotextiles, and considering the sustainability aspects as defined in the 2030 Agenda of the United Nations (UN 2015), it appears necessary to review the hesitation, and to discuss this in context with the available experience and case histories.

Hesitation regarding the use of geotextiles as filters and/or drains for embankment construction can be split into the following four key aspects:

- Uncertainty with regard to the design of the filter/drain.
- Uncertainty of the long-term behaviour of the material itself (i.e. the influence of blinding or clogging).
- Construction damage affecting the performance.
- Unknown or changing loading and environmental parameters affecting the performance.

All these factors can potentially pose a structural risk to the embankment dam. The concerns listed above are discussed later in more detail, although it should be noted that the intention of this paper is not to discuss different design approaches. Similar to a conventional design of a filter or drain with granular materials, a diligent and robust design process is essential when designing a geotextile filter. The intention of this paper is rather to provide arguments and assistance to consider geotextiles as filters and drains for future projects.

3 DESIGN OF FILTERS AND DRAINS

3.1 *General*

At the time that most currently available guidelines and codes were published, design methods and conformance testing of geotextiles was not very sophisticated. Today there exist several design documents and guidelines publicly available, partially officially released, partially as scientific papers, which represent the current state of knowledge. For instance, the guideline DWA M 511 by the German Association for Water and Wastewater describes the filtration with geosynthetics (DGGT 2017). Similarly, the various parts of the technical report published by the Working Group 6 of ISO TC 221 address the design with geotextiles in ISO TC 221-3 2023 and ISO TC 221-4 2023. There are also well regarded geosynthetic industry references like Koerner's "Designing with Geosynthetics" textbook (Koerner 2012).

A key design consideration for a filter, whether constructed using a granular material (such as soil) or a geotextile, is to ensure that the correct "pore size" is used. This will ensure that water is allowed to migrate, but that fines are prevented from clogging the filter and that the embankment material is restricted from being washed out of the structure. For granular materials, this pore size is generally linked to the grain size distribution. Various testing and design methods exist to determine this correct pore size and the relevant parameter can be referred to as apparent opening size (AOS) (see ASTM D4751, ASTM 2021a) or the characteristic opening size (O90) (see ISO 12956-2019, ISO 2019). Refer to Blond et al. (2015) for additional details on these parameters.

Irrespective of the design method selected, this design approach links the effectiveness of a filter to a single value instead of a particle size distribution as is often used when designing a granular filter. From a design point of view, it is important to note that there are two ways to ensure filter stability. Both ways have to ensure that particles are held back and/or do not clog the filter. In the case of a filter with larger pore sizes, such as a woven geotextile, this is achieved by generating bridges of larger soil particles (also referred to as a 'bridging network' or 'graded filter zone'), see Aydilek (2012). In the case of non-woven geotextiles this is achieved by pore sizes which are small enough to prevent fines from passing through, thereby only allowing a small filter-layer to form. Figure 1 illustrates the two different design approaches. It is clear that the hydraulic capacity of a finer filter (non-woven geotextile) is less compared to a coarser filter (woven geotextile). In addition, the risk of clogging is potentially higher for the finer non-woven geotextile filter, compared to the coarser woven geotextile filter.

a)

b)

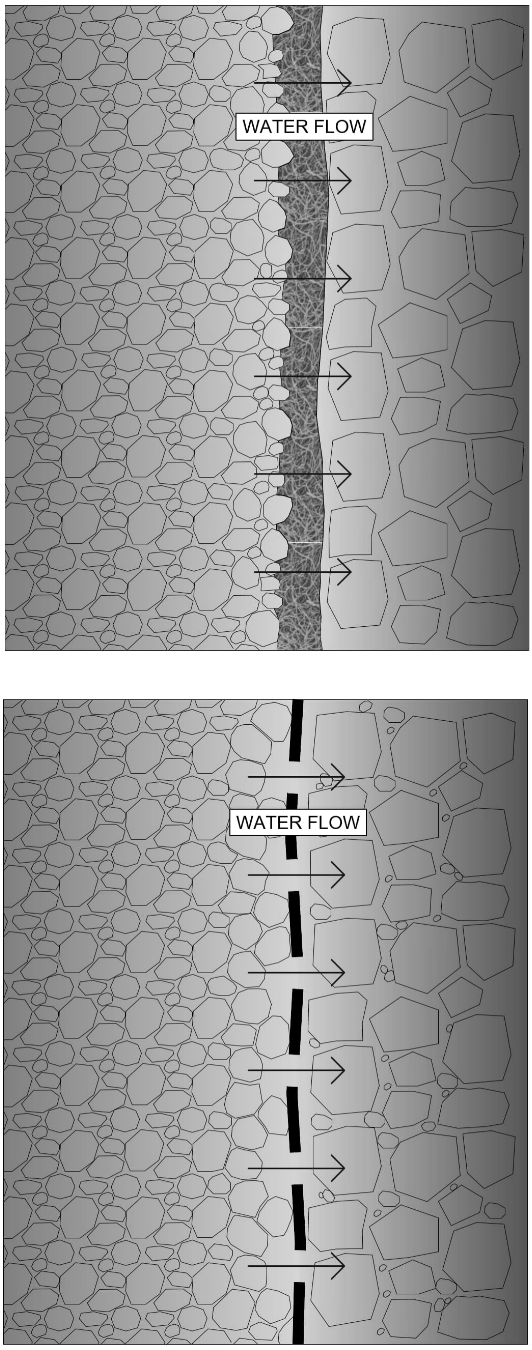

Figure 1. Schematic sketches showing the design approaches using a) non-woven geotextiles and b) woven geotextiles

As for granular filter materials, the selection of the geotextile filter depends on the base material. Non-woven, needle punched filters are an example of smaller opening sizes, especially when calendared (final production step of passing between heated rollers), whereas woven geotextiles are an example of a geotextile filter with larger opening sizes. Note that the applied compressive stress the geotextile is exposed to is likely to affect the pore size and needs to be considered during design.

New geotextile filter design methods are also becoming available. These were developed through a synthesis of the existing body of knowledge, combined with laboratory testing to validate the new design methodology (Sack et al. 2023). Compared to the use of a single parameter as design criteria, such as AOS or O90, these design approaches apply multiple retention criteria and seem to be more resilient especially for gap graded soils in combination with non-woven geotextiles. These methods generally make use of the bubble point test (BBP), as described in ASTM D6767 (ASTM 2021b).

Blond et al. (2015) proposed and discussed advantages and limitations of different experimental techniques for the determination of geotextile opening sizes.

Detailed drain design aspects are described in the working draft of TC221 WG6 N263 PG4 TR 18228-4 (2018) or GRI Standard GC8 (GRI 2013). Hydraulic considerations and long-term functionality are key design aspects for drain designs. Both references emphasize the need to conduct water flow capacity tests as the capacity is influenced by the applied compressive stress on the geotextile, see for instance EN ISO 12958 (CEN 2020). Further, the working draft of ISO TC221 WG6 N263 PG4 TR 18228-4 (2018) suggests testing and considers various reduction factors for uncertainties like clogging. Combined, these factors can be as large as 35!, see Koerner (2012) or ISO/NP TR 18198 for more details.

3.2 *Clogging of filters and drains*

In order to ensure the long-term functionality of filters or drains, and in order not to compromise the safety of embankment dams, the question of potential clogging (accumulation of particles within the fabrics pores) and blinding (a layer of fine particles building up on the surface of the geotextile) is of utmost importance.

By reducing the pore sizes, clogging of filters or drains reduces the functionality by some orders of magnitude. Irrespective of the mechanism causing clogging, clogging will occur to a certain extent. What is important to note, however, is the fact that in most circumstances a clogged geotextile will still have a higher hydraulic conductivity than that of the soil itself (Bhatia 1995). Nevertheless, the design needs to account for the possibility of clogging, which can be caused by the following:

- Insufficient design considerations (incompatibility between the base material and geotextile or reverse/alternate flow conditions.
- Biological processes (bacterial growth).
- Chemical processes (ochre clogging and sintering).

Design considerations and the need for a diligent design philosophy including testing, have been discussed already. What is more relevant is to investigate the reasons for biological and chemical clogging.

Biological clogging requires the presence of bacteria able to buffer iron and manganese. The bacteria required to initiate the ochre process (Gallionella, Leptothrix, Siderocapsa and Siderococcus) as well as the biological clogging processes themselves, are well known as this is a frequent problem in water well construction (e.g. Krems 1980).

Chemical clogging can only take place in certain environments and requires, amongst others, the presence of dissolved iron and dissolved oxygen as well as specific pH values and a redox potential. The decisive factors described above can be summarized as an rH value (Hoelting & Coldewey 2013). Chemical clogging is likely to occur for rH-values $\geq 14{,}5 \pm 1$. The identification of the rH value and the chemical clogging mechanisms are also well understood. The research was initially conducted for water well design and construction (e.g. Haesselbarth & Luedemann 1967). The same methodology should be applied for a filter design with geotextiles.

In contrast to research and design approaches borrowed from other, partially similar disciplines, such as the construction of levees, riprap or water well construction, is the fact that access and exchange of oxygen is certainly more restricted inside embankment dams and no direct contact with ambient atmosphere is likely. Ingress of oxygen is limited to oxygen available in the voids and water. It is therefore reasonable to state that processes will, if at all, take place at a far slower rate compared to those processed that occur in direct contact with or very close to the atmosphere. Robust design approaches considering flow reduction are suggested. Reduction due to clogging is usually of the order of 20% in anaerobic conditions and 12–100% in aerobic conditions (Aydilek 2012).

It is clear that both biological and chemical clogging are aspects which have to be considered in the design process when designing a granular filter or drain as well.

A combination of different conditions is also possible and might have to be considered.

3.3 *Blinding of filters and drains*

Blinding of geotextile filters and drains is another design aspect which needs great care and attention. The impact on the hydraulic properties in the case of blinding may be far more significant than in the case of clogging. In some cases eventually causing a filter to act as a barrier, rather than a drain. Blinding of a filter or drain occurs when the hydraulic flow moves the base soil particles with dimensions smaller than geotextile pores and the fines are held back in the geotextile at the soil-geotextile interface. Although the rheological properties are different, the mechanism can be compared to the formation of a filter cake when stabilising cut-off walls with bentonite.

Again, the susceptibility of a geotextile to blinding can be evaluated in a rigorous design approach compromising state of the art laboratory tests. In the case of blinding, this could be the gradient ratio test (see ASTM D5101-90, ASTM 1990).

3.4 *Chemical stability and long-term durability*

The silt and fine sand fractions, high or low pH-values, as well as extreme temperatures will certainly affect the performance and long-time behaviour of a geotextile filter. The mechanism of degradation for the different types of materials used for geotextiles are well understood, particularly hydrolysis for polyester geotextiles in high or low pH environments, and reliable and well-accepted testing/specification guidance and codes are available, like GRI GT13a (GRI 2017).

Many embankment dams are often however used as water storage facilities, either as drinking water or for irrigation purposes. The boundary conditions in these applications are mostly not adverse and rather support the use of geotextiles. Several successful examples can be used to verify this, the oldest being the Valcros dam in France dating back to the 1970s. Note that the conditions might be quite different in mining-related applications.

3.5 *Construction damage*

An often-used argument against the use of geotextile filters or drains is the fact that construction damage might occur, and that the damage will impact the functionality and integrity of the geotextile filter. The following construction damage could occur:

- structural damage during construction.
- poor installation.
- penetrations.
- excessive strains during construction.

It is currently industry standard to establish well thought-through Quality Assurance (QA) and Quality Control (QC) procedures to prevent or limit construction damage. Meaningful and practical experience has been gained with landfill design and construction projects. Especially in the case of hazardous landfills, it is obvious that filtration, drainage and lining must meet the highest standards for environmental protection and should not be compromised. Examples and guidelines on how to set up a working QA/QC procedure are described for instance in the South African

Standard SANS 10409: Design, selection and installation of geomembranes (SABS 2020).

One major advantage of a granular filters is their "self-healing" capacity in the case of material loss, for example due to piping. This is certainly more of an issue for geotextile filters but can be overcome with a stringent QA/QC procedure, thereby avoiding damage in the first place.

3.6 *Unknown or changing input parameters affecting the performance*

Instead of highlighting the concerns repeated for almost four decades, the authors would like to emphasize the fact that geotextiles in general are manufactured in a controlled environment with constant, rigorous manufacturing quality control measures being implement. Compared to granular filter materials, the natural variability of geosynthetic filters is generally much less, resulting in less uncertainty in the engineering properties of the filter. With significantly more effort, the properties of a granular filter can be quality controlled as well. However, what is more difficult to control is the uniformity of the granular filter itself.

4 CONCLUSION AND OUTLOOK

Considering the fact that almost 40 years has elapsed since some of the guidelines and recommendations with regard to the use of geotextiles as filters and drains in embankment/fill dams have been published, it is timeous to review the current state of practice. The "we have always done it like this" approach needs to be questioned. A paradigm shift both from consultants and dam owners is required and recommendations and design codes need to be updated.

It is the authors' opinion that the often-referred to arguments not to use geotextiles in embankment construction are outdated and should be reviewed. Specifically, these arguments should reflect the latest research in the area. Some counter-arguments have been provided in this paper with perhaps the most convincing aspects being the following:

- the significantly increased knowledge regarding design, testing and long-term behaviour of geotextiles.
- the positive experience in cases where geotextile filters that have been installed in embankment dams.
- the positive experience gained in landfill design, where the environmental conditions in general are far worse than traditional water dams (Rowe and Jefferis 2022).
- the fact that resources can be saved when using geotextiles compared to a natural granular material.

It is also acknowledged that the hydraulic gradients in embankment dams may be significantly higher than in other applications. This is certainly a key design aspect which needs to be accounted for.

Implementing a stringent QA/QC procedure further limits the risk of damage to the geotextile which is especially important in the case of high hydraulic gradients to avoid piping, for example.

Nevertheless, it is clear that the design approaches when considering geotextiles as filters and drains should be very stringent and the functionality of a preferred solution should be supported by extensive and careful laboratory tests, preferably large-scale tests. All the above-mentioned design aspects are however also recommended when designing with granular materials.

It should be pointed out that particular care is required when dealing with dispersive soils, internally unstable soils (especially in the silt and fine sand diameter ranges) and "unusual" water chemistry.

Finally, the authors want to point out that the argument limiting the use of geotextiles to areas of a dam which are easily accessible for repairs in case of an underperforming drain or filter, seems to limit design options for engineers significantly. Remediation works in a core are certainly a costly exercise, but are possible and in no way different than reinstating base drainage on a landfill. Obviously, underperforming drains or filters need to be considered in the design process, and adequate instrumentation as a suitable tool to assess the functionality and deal with the risk thereof is required.

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