Geotextiles as Filters and Transitions in Fill Dams

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ABSTRACT

The development of embankment dam engineering in South Africa over the last century has been met with many challenges, one of which was the use of geotextiles as filters. The historical design philosophy and use of geotextiles is reviewed. Recent investigations into design practice and insitu geotextile filter performance at various dam sites are described. It is concluded that geotextiles may be used as filters where replacement is practicable and as adjuncts to the filter system of embankment dams where replacement is impracticable.

1 INTRODUCTION

The use of geotextiles in embankment dams may serve the function of drainage; filtration; separation; reinforcement or liner protection. The purpose of this article is to present details of investigations into the use of geotextiles as filters or separators within embankment dams in South Africa. Comments concentrate on the functions of filtraton and separation. Details of durability and strength are not reported here.

2 HISTORY OF EMBANKMENT DAM ENGINEERING IN SOUTH AFRICA

The greater part of South Africa is semi-arid to arid and even the narrow strip along the east and south coast is only moderately wet. To enhance the standard of living and to facilitate economic development the scarce water resources of the country must be utilized as efficiently as possible. This policy has been evident ever since the first large dams were constructed in South Africa. (Elges et al, 1994).

The first large fill dam was the Van Wyksvlei Dam having a height of 15 metres and a crest length of 311 metres which was completed in 1884. To date 2139 fill dams with a maximum height of up to 12 metres have been registered in South Africa with a further 647 embankment dams having a crest height in excess of 12 meters.

Design of these early embankments was by empirical methods. Construction techniques involved loading scotchcarts with soil by shovels and end tipping of the soil which was then compacted by trampling by teams of oxen or sheep. With the passage of time design and construction methods have become quite sophisticated.

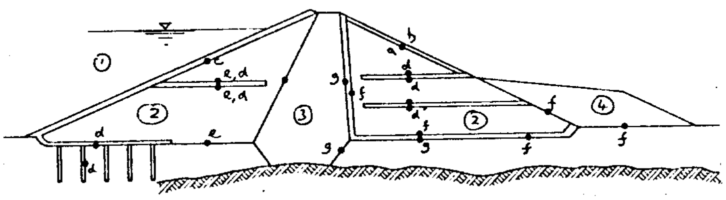
Developments in construction materials technology did not go unnoticed. The first dedicated geotextile manufacturing plant came on line in 1978. Today woven; non-woven and knitted geotextiles are produced locally and this variety is supplemented by importers.

3 THE USE OF GEOTEXTILE FILTERS IN FILL DAMS

The use of geotextiles in embankment dams is not new and several authors have reported on this in the past. There is however only limited pertinent design information in the literature on geotextile filters in fill dams. The International Congress on Large Dams (ICOLD) has published its philosophy on this subject in its Bulletin no. 55 of 1986. Dam design engineers in the 78 member countries of ICOLD usually refer to this document when considering the use of geosynthetic filters in embankment dams.

Possible applications of geotextiles as filters and

transitions in fill dams include: beneath upstream and downstream armouring; between toe drains and insitu material; either side of chimney and blanket drains; as transitions either side of core material and as consolidations expedients both in and beneath shell material.
(See figure 1)



1. Reservoir
2. Fill
3. Core
4. Granular fill

Figure 1: Schematic section of fill dam showing possible filter locations (after ICOLD Bulleton 55).

In South Africa geotextiles have successfully been used in the 51m high Kilburn Dam; 56m high Hans Strijdom Dam and the 43m high Braam Raubenheimer Dam amongst others. The geotextiles were installed during 1977 and 1978 while the embankments were under construction. Geotextile applications in these dams include the following:
Braam Raubenheimer composite dam:- under riprap; surrounding the toe drain and blanket drain. (See figure 2).
Kilburn embankment dam:- beneath the upstream riprap; on the downstream face of the chimney drain to supplement the natural filter and surrounding the toe drain. (See figure 3).
Hans Strijdom rockfill dam:- on the upstream and downstream face of the sloping central core between the core and sand filter to supplement the granular filter system. (See figure 4).

By the early 1980's more than 30 large dams had either been constructed or were under construction, in which geotextiles had played a role in the filter system.

4 DESIGN CONSIDERATIONS IN THE 1970'S

4.1 Required performance life and accessibility

The potential use of geotextiles in dams may be divided into groups viz. construction expedients and permanent uses. Construction expedients include uses such as in temporary haul roads and drainage of fill material to speed consolidation. The group of permanent uses may be further subdivided into applications where replacement is practicable and where replacement is inpraticable. When geotextiles are used beneath thin coverings of embankment protection (riprap) on the upstream or downstream face or in the toe drain, replacement may be practicable. This certainly is not possible when geotextiles are used as materials separators or filters to the drains in either the embankment body or the foundation of the dam.

The longer the performance life required and the less accessible the proposed geotextile application is the greater the degree of conservatism that was required in the design.

4.2 Loads and performance

The extent to which filter performance is critical to the safety and satisfactory performance of a dam can be related to the nature and duration of the flow against which protection is required, the extent to which failure of the filter is critical to the safety of the structure, and the practicability of repair if failure occurs.

Thus in each individual case the loading conditions to which the filter may be subjected during its life was considered.

Conditions considered included hydralic gradient; probable deformations and strength requirements for installation and construction. This influences the strength; puncture resistance and conformability parameter requirements. The imperatave filtration requirements of base soil retention and permeability were also addressed.

4.3 Example of early use

The Hans Strijdom dam is situated on the Mogol River in the North-West of South Africa. The Mogol River is a tributary of the Limpopo River which forms the boundary between South Africa and Botswana and South Africa and Zimbabwe.

The 56m high rock-fill embankment has an inclined core which was chosen as being better to accommodate differential settlement between core and rock-fill (Hollingworth and Druyts 1982). Of the early concerns to the designers was the poor quality of the available core material combined with the difficulty of obtaining filter materials. This is reported to have been the main problem in the design and construction of the dam.

The available core material consisted of a fine grained sandy soil with a permeability of about $1x10^{-6}$cm/s. While this permeability is not ideal it was considered reasonable. The more problematic

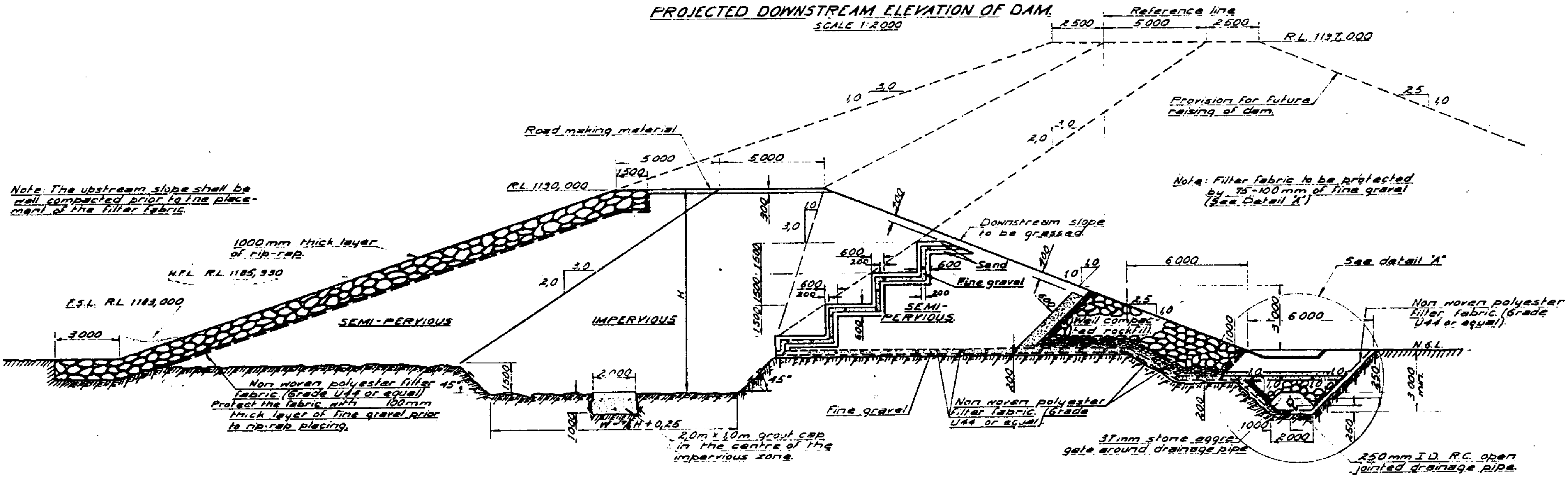


Figure 2 Typical section through Braam Raubenheimer Dam

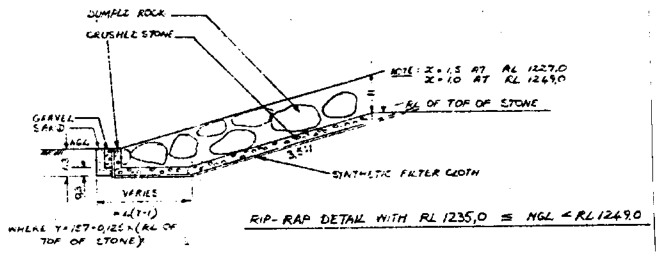


Figure 3 Detail of geotextile use on upstream face of Kilburn Dam

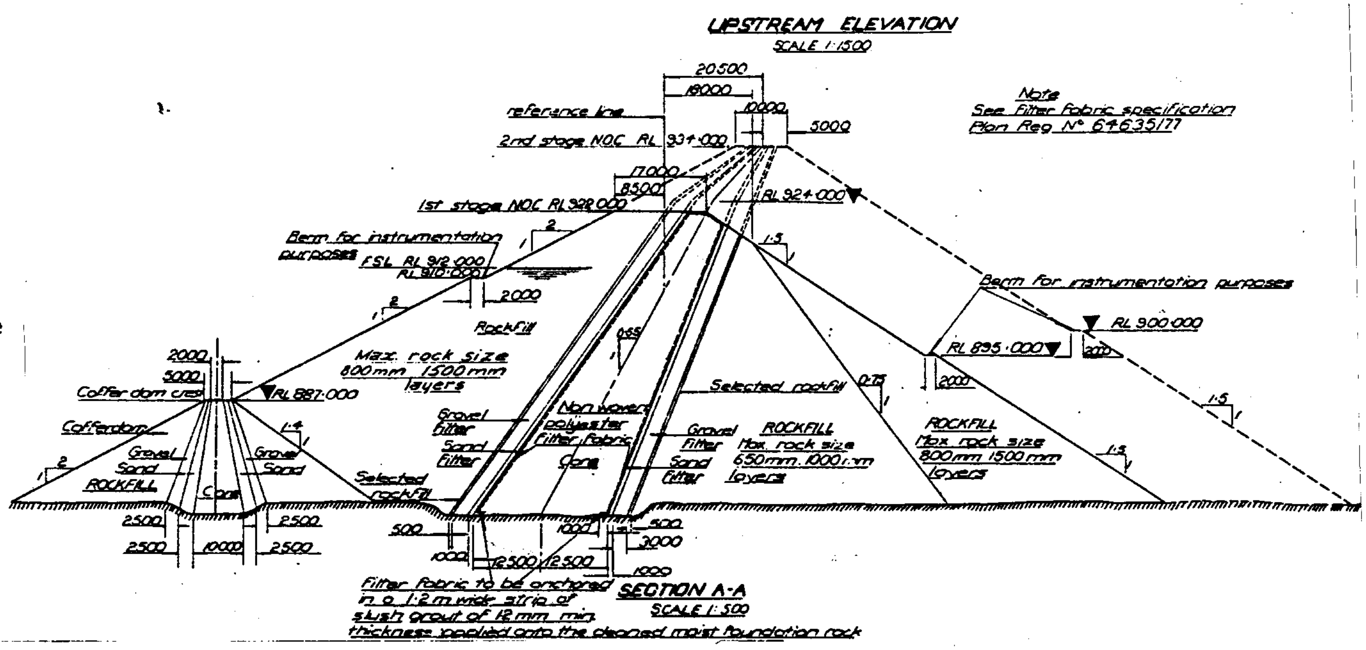


Figure 4 Use of geotextile as an adjunct to the sand filters in Hans Strydom Dam

characteristics of soil were the liquid limit of about 20 and a plasticity index of between 6 and 10. For a rockfall dam with relatively thin core, suitable core material should have the following characteristics: plasticity index 15 - 20, liquid limit 30 - 40, linear shrinkage 6 - 8%, permeability $1x10^{-8}$cm/s. No such suitable materials existed within a reasonable haul distance. It was concluded that the core would be susceptible to cracking and piping. Thus special care was taken with the core configuration and filter design.

The initial design called for a 3m wide sand and 3m wide manufactured gravel filter. Problems were encountered in obtaining sufficient quantities of suitable sand. It was decided therefor to reduce the thickness of the sand filter from 3m to 1m and to add a layer of continuous filament non-woven needle punched geotextile between the core material and the sand filter. While there was some doubt as to the durability of the geotextile it was felt that even if the fabric did deteriorate with time, it would at least offer protection to the core against piping during the critical first filling of the reservoir and during the first few operating years when post construction settlement and core cracking would be expected.

A 340g/m^2 continuous polyester filament non-woven needle punched geotextile was chosen to replace a 2m width of sand filter.

Installation consisted of sandwiching the geotextile between two 25mm thick layers of grout on the foundation over a 1m wide strip beneath the core. The geotextile then passed through a bend and proceeded in the line of the filter with successive lifts being joined by sewing. The geotextile was damaged regularly by the heavy earth moving and compacting machinery and these damages had to be repaired continuously.

Regular inspections of the toe drain show no piping is taking place and in fact a remarkably low seepage rate is noted.

5 DEVELOPMENTS IN TECHNOLOGY

In 1984 the Department embarked on an investigation into the suitability of geotextiles for use within earth embankment dams. TThis was as a result of the question as to whether a geotextile could be used as primary internal filters. This investigation included a review of the then available design criteria. Problems were encountered in assessing the pore sizes of locally available geotextiles as required by the various criteria.

It was decided to persue the route of laboratory soil-geotextile compatability testing. The initial form of test followed included variations of the permeameter pot type of test and the gradient ratio test. To evaluate the effects of high hydraulic gradients on concentrated leaks a large diameter triaxial cell was modified for a test programme. This culminated in the development of the interface flow capacity (IFC) test reported by Legge (1990). Evaluation of this latter test method is ongoing.

5.1 Present design procedures

The general ICOLD philosophy published in its Bulletin 55 of 1986 is followed. Design procedures have however advanced and a desk top analysis is undertaken following procedures as published by John (1987) and Koerer (1990).

Once the desk top analysis has been completed and suitable geotextiles identified, these are subjected to soil-geotextile compatibility testing before final selection.

The final selection includes consideration of minimum strength and deformation requirements of the geotextile. These perameters need to take account of both the short term loading expected during installation and construction as well as post construction loads and deformations. While overall embankment settlement may be low, local stresses and strains may be high due to differential settlement or drying shrinkage of soils. It is for this reason that a geotextile needs to maintain its restraining characteristics, even after local concentrations of stresses and strains. Legge (1986) reported on the substantial changes in pore size of a geotextile on elongation. Of concern is the extent to which woven tape and staple fibre products pores elongate when the fabric is placed in tension.

Note all dams shall be designed on the understanding that there is a significant risk that the core will crack and that the possibility of internal erosion of the core has to be allowed for in the filter design (McKenna, 1989).

5.2 Future designs

For further development in geotextile applications, the durability and construction damage need to be quantified for use by designers.

It is not necessarily the responsiblity of specifiers alone to resolve these questions. Suppliers may soon be able to provide superior products.

6 RECENT EXPERIENCES

Over the years the authors have been fortunate enough to be involved in several investigations into geotextile filter performance with time. Some of these findings are reported below.

6.1 Ergo Tailings Dam

In October 1985 the failure of the perimeter strip drains during the development of the 85m high Ergo Tailings dam was reported. During a site investigation the sub-surface drainage system of the cyclone deposited Gold Tailings dam perimeter walls appeared to be blocked at the exit to the wall of outlets numbers 13 and 14. The drainage outlets consist of a uPVC pipe buried in 19mm stone and enclosed in a geotextile. The geotextile was a continuous filament non-woven needle punched fabric having a mass of 180g/m^2. A layer of crusher dust approximately 100mm thick covered the sub-surface drain. This was done to protect the geotextile from damage (mechanical and uV light etc.) prior to tailings deposition. The drains were partially uncovered at the toe of the wall. It was noted that the outside of the originally grey geotextile had taken on a redish brown colour typical of iron oxide precipitate. The sub-surface drain was flowing under pressure indicating that the fabric had at least partially blocked. Geotextile samples were cut from the drain. The inside of the geotextile was covered with a black slime.

Investigations using an electron microscope, gas chromatography and chemical analysis showed that an iron oxide had precipitated and that despite the presence of cyanide and arsenic a bacteria (black slime) had developed which was feeding off of the iron oxide.

While the bacteria serve the purpose of reducing the precipitate it was feared that an excessive growth of this bacteria would block the drains to an unacceptable level. A solution was sought which would control the development of bacteria within the drainage system. A "P" trap was placed on the outlet pipe. This "P" trap could be removed and refitted as and when seen fit. The use of the "P" trap meant that the sub-surface drain could be changed from a saturated anaerobic condition to an aerobic condition. Sudden changes in habitat within the drain killed off the bacteria. By regular changes in environment the growth of the bacteria could be controlled.

6.2 Zoeknog Dam failure

In January 1993 the 40m high homogeneous earth embankment Zoeknog Dam failed during first filling. The embankment material consisted of a fine grained braodley graded weathered granite which appeared to be marginally dispersive. The embankment contained a chimney and blanket drain which exited to a toe drain. Extensive use of a 270g/m^2 continuous filament non-woven needle punched geotextile was made: beneath the upstream riprap; either side of the sand chimney drain; above and below the sand and stone blanket drain and beneath the toe drain.

Investigations showed that while a piping failure had taken place through the foundations of the embankment beneath the level of the blanket drain and that internal drainage system had in fact never intercepted flow.

Excavation of the drainage system at various points in the embankment revealed that while the geotextile had served adequately as a separator, extensive damage to the fabric has taken place where the fabric had been laid over the 38mm stone upper layer of the blanket drain. Unsewn joints which had been placed with a specified 300mm overlap had also pulled apart. Further more the geotextile has been damaged (punctured) by the sharp aggregate.

These observations confirmed the philosophy that the use of a geotextile as a primary filter in critical applications in a large embankment stands a high risk of failure.

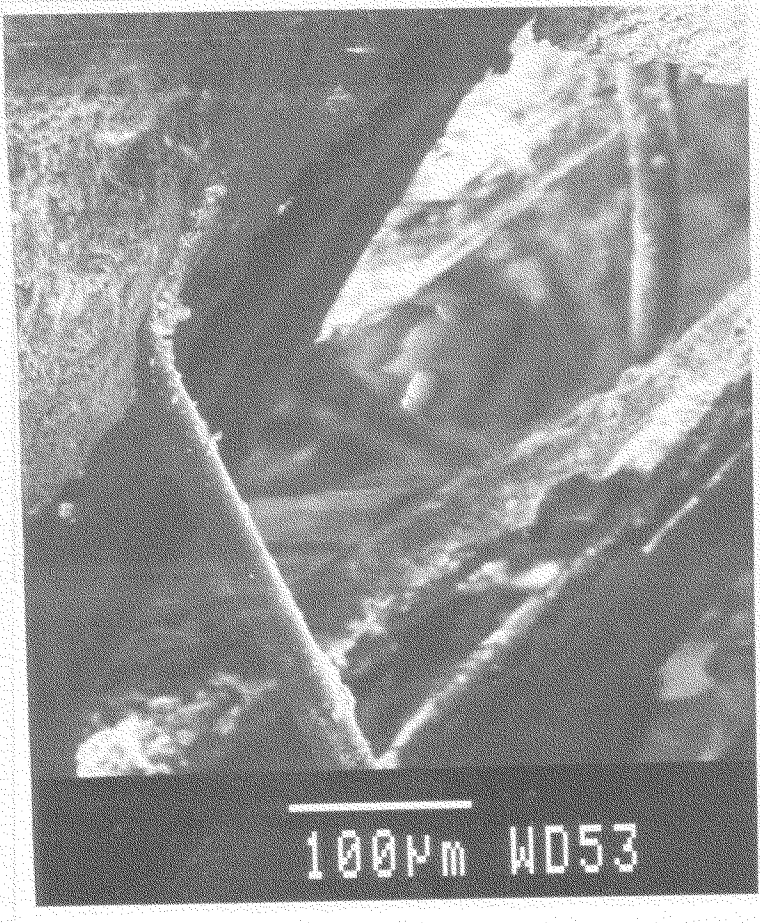
6.3 Vondo Dam

The 13 year old 28m high Vondo Dam currently being raised to 41m gave the authors an opportunity to recover geotextile from beneath the riprap on the upstream face.

Insitu observations showed that the geotextile had worked adequately as a filter in that the fine fraction of the homogeneous embankment material had migrated through the geotextile and discoloured the over lying riprap in the zone adjacent to the geotextile. Fabric recovered was of the continueous filament non-woven needle punched type and having a mass of 340g/m^2. The soil at the interface had developed a reverse filter over a length of approximately 2mm.

Limited strip tensile testing of the fabric showed that after 13 years the polyester fabric retained a strength in excess of 80% of its initial strength.

Photograph 1: Partial organic clogging of a geotextile



7 CONCLUSIONS

Having gained experience with the use of published filter design criteria and philosophies and evaluated post construction performance the following conclusions are made:

Conservatism in design should reflect the extent to which filter performance is critical to the safety and satisfactory performance of the dam.

The current range of geotextile design criteria and laboratory compatibility test methods give designers a fair indication of expected filter performance under norman conditions.

Factors other than positive retention and clogging need to be addressed when considering the use of geotextiles within embankments. Such factors may include the relationship between stress, strain and pore size; the durability of polymer used and the ability of the geotextile to provide a continuous filter barrier.

The use of geotextiles should be confined to the outer serface or the area which can be accessed if necessary to effect repairs.

In exceptional cases where much higher risks are acceptable and the life of the embankment is relatively short the use of geotextiles as primary filters within smaller dams may be considered. It is good practice to confine the use of geotextiles within embankments to construction expedients or as an adjunct to the chimney and blanket drains where their purpose is primarily to hold back core material and thereby prevent contamination of the main filter. The geotextile should not be seen as an alternative to the granular filter.

Where geotextiles are used as adjuncts to the filters protecting the core, favourable consideration should be given to selecting continuous filament non-woven needle punched type geotextiles due to their superior post deformation retention capabilities.

8 ACKNOWLEDGEMENT

The authors wish to thank the Director General of the Department of Water Affairs and Forestry for permission to publish this paper.

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