CASE HISTORY: MOKOLO DAM - SUCCESSFUL BIDIM® GEOTEXTILE SERVICE IN A MAJOR ROCKFILL DAM SINCE 1979

Peter L Davies
Kaytech Engineered Fabrics, Durban, South Africa

INTRODUCTION

Some people make history, and where the use of geotextiles is concerned, in South Africa one man who really stood out in paving the way to their universal acceptance was WCS ('Bill') Legge, who served as Chief Engineer in the Civil Design Department of the then South African Department of Water Affairs from 1972 to retirement in 1986. The author was privileged to be able to work with him over a number of years, on the incorporation of geotextiles into South African dams. It is interesting to note that his son Kelvin is following in his father's footsteps and is now an internationally-recognised authority on the use of geosynthetics in the built environment, particularly in the field of filtration and drainage, and of the lining of waste management facilities.

WCS (Bill) Legge

As described in the International Commission on Large Dams (ICOLD) Bulletin 55 of 1986 "*Geotextiles as filters and transitions in fill dams*" (now under revision by the South African National Committee on Large Dams, under the lead of Kelvin), and commencing nearly forty years ago, some significant dams were constructed in South Africa utilising geotextiles in many of their critical filter zones. In all the years of operation since then, none of these dams have been reported as showing any distress attributable to the use of those geotextiles. One of these structures, Hans Strydom Dam ("Mogol", and now designated Mokolo Dam) was designed internally by DWA engineers working under the direction of Bill Legge. The dam is on the Mokolo River, in the Limpopo Province of South Africa, with a catchment of 4 374 km² and a capacity of 151 million cubic metres. It lies on the northern slopes of the Waterberg Mountains, about 50 km south of Lephalale (Ellisras) and north east of the Marakele National Park. This dam is well suited for water sports, camping and day visitors, and includes a picnic area for day visitors and basic camping sites. Mokolo nature reserve at the dam is relatively small, but attracts visitors due to the picnic and fishing spots around the dam (bass up to 4.6kg have been caught there).

This study is about that dam, the design and construction of which is well documented (Hollingworth and Druyts 1982) and intends *inter alia* to show by the dam's ongoing success, that the current reluctance by the regulatory authority to approve licence applications for designs incorporating geosynthetics as adjuncts in critical applications, as well as in non-critical applications, is, in the writer's opinion, an overly-conservative approach without technical or historical justification.

In suggesting a way forward, this article proposes the simultaneous employment of benefits from geotextile and granular filter materials in composite filters in some critical applications, including the internal drainage of embankment dams where the nature of the granular material or the permeant may induce detrimental changes in safety with time. In such applications the geotextile serves as an adjunct to the granular filter and the granular filter supplements the geotextile filter performance, with resultant reduced risk of failure (Legge, 1990 & 2012 and Davies *et al* 2012). This is the approach the designers adopted on the Hans Strydom Dam back in the mid-70s.

1. BACKGROUND

A worldwide review of dam failures (ICOLD Bulletin 99 of 1995) confirms the importance of preventing internal erosion or piping in critical applications, especially during the first decade of service. Furthermore the use of filters and drains in critical applications such as in dams requires filter systems to perform under diverse conditions of hydraulic gradient; wetting and drying cycles; stress and strain; with varying quality of the permeating fluid. These conditions have an effect on the short and long term performance of filters and drains.

1.1 Geosynthetics in Dam and Reservoir Engineering in South Africa

Geotextiles have and are being used in small and some large dams, between base material and drainage material in toe drains; blanket drains and chimney drains as well as under rip-rap on the upstream face and occasionally on the downstream face. The use of geotextiles as primary filters and adjuncts to granular filters within earth embankment; rockfill and tailings dams is an established practice (Elges et al 1994 and Davies et al 2012), and prior to the formation of the DWA Dam Safety Office in 1986, many significant South African Dams incorporating geotextiles were designed and constructed by the DWA. It is again emphasised that none of these dams has shown any distress that can be linked to the use of these geotextiles.

The ICOLD bulletin no 55 of 1986, "*Geotextiles as filters and transitions in fill dams*" also recommends that while geotextiles may be used as the primary filter in non-critical applications (i.e. where accessible for replacement in the event of failure), the use of such materials should be limited to adjuncts in critical applications such as internal chimney and blanket drainage filter systems. This bulletin contains an appendix of multiple examples of geotextile use in large dams in many countries during the early years of this type of application.

Mokolo Dam (formerly Mogol, Hans Strijdom and before that Wildebeestfontein Dam) is a 57 m high rockfill embankment dam (designed and constructed by the then DWA) that used a 340 g/m² nonwoven continuous filament needle punched polyester geotextile, ('bidim U44', today's bidim A8) as an adjunct to the clay core protection filter (see Figures 2 & 3). It may be interesting to note that the persons in Figure three (picture taken in 1979 by the world-famous geosynthetics pioneer Professor J.P. Giroud, then of the University of Grenoble) are (L-R) James Butler (DWA), Frans Druyts (DWA), a much slimmer than now Peter Davies (Kaytech) and Frank Hollingworth (DWA).

Figure 2: Mokolo Dam under construction (1979)

Figure 3: Mokolo Dam - Geotextile as an adjunct between core and graded filters

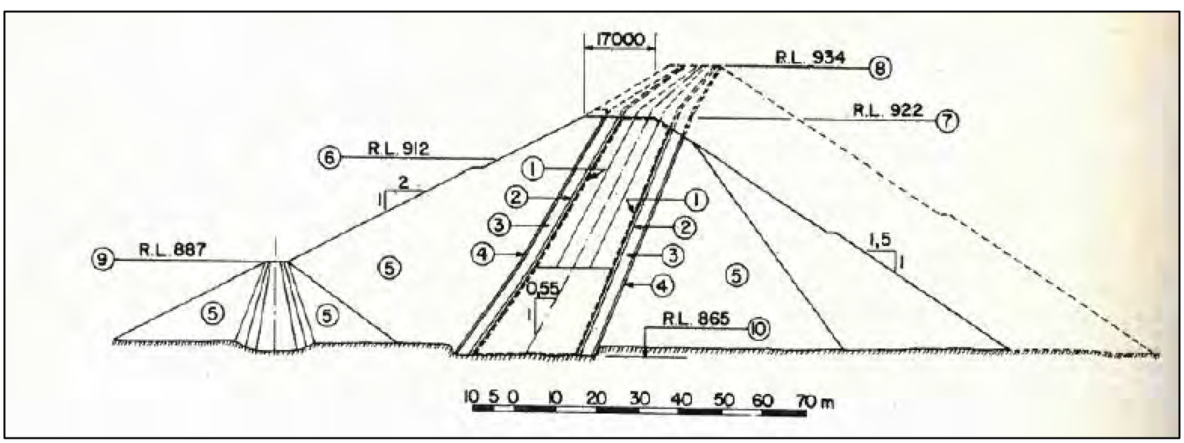

Figure 4: Section through Mokolo Dam

1) Geotextile, 2) Sand filter, 3) Gravel filter, 4) Selected rockfill, 5) Rockfill, 6) Full supply level,
7) Initial crest level, 8) Final crest level, 9) Cofferdam crest level, 10) Lowest foundation level

Figure 5: Mokolo Dam today, with the spillway to the left.

2. WHAT CAUSES DAM FAILURES

ICOLD (1995) provides a statistical analysis of dam failures. Some 2,2 % of dams constructed prior to 1950 failed, whereas since 1951 only 0,5% of dams constructed have failed. The percentage of failures is independent of dam type, and the ratio of number of dam failures of given height over number of dams constructed of given height is approximately the same irrespective of given height. In the case of earth and rockfill embankment dams the primary cause of failure is due to overtopping and the second most common cause is due to internal erosion either in the embankment or through the foundations. Erosion of foundations is also the second most common cause of failure of concrete gravity dams. It is important to note that in the case of earth and rockfill dam failures that most take place in the first 10 years after construction, and of these failures approximately 90% take place within the first year. In South Africa the most common dam types are earth and rockfill dams, with approximately 91% of these large dams being earthfill. This statistical analysis confirms the importance of competent filters to protect against piping, in particular upon first filling of the dam.

6. COMBINING GEOTEXTILE AND GRANULAR FILTER PERFORMANCE

Filters in critical applications are relied upon to prevent erosion of base material and reduction of pore pressures for stability, as well as to induce self-healing in the base material so as to prevent concentrated flows.

The current practice of relying on granular filters in critical (inaccessible) applications requires thick and clean filter systems which do not change their characteristics with time. Granular filters however may indeed change with time due to the effects of physical, chemical and biological clogging as well as due to a physical change in the granular material due to permeant induced internal erosion or particle weathering such as in acid mine drainage. In such circumstances the granular filter may lose its self-collapse characteristics.

Geotextile filters are thin and can be easily damaged during careless construction. To some thinking their durability has also yet to be proven, despite their successful use since the 1950s (Barrett, 1966); however their chemical compatibility and porosity along with tensile strength offer significant value in the short to medium term.

In the pursuance of economic and safe filter systems while maintaining a cautious approach, it is suggested that the short term advantages of geotextile filters should be used to enhance the long term reliance on granular filters by combining the two materials in an upstream geotextile and immediately adjacent granular filter, both being designed to be compatible with the upstream base or core material. This would allow for thinner and hence more economical composite filter systems in which the geotextile serves to increase the rate of self-healing at concentrated leaks while simultaneously maintaining the granular component of the filter in a clean condition (as was the case of Mokolo Dam). The granular filter transmissivity is thus not reduced and the risk of embrittlement or loss of self-collapse potential is further reduced.

Furthermore in order to construct composite filters, the conventional method of granular-only filter construction requires amendment and focuses attention on the filter system throughout the construction period. This increased attention driven by the presence of a geosynthetics component reduces the risk of contamination of the granular component and similarly reduces the risk of developing a window in the filter system.

The statistical analysis of dam failures shows that the second most common cause is due to erosion and that 90% of these failures take place within the first 10 years during which time polymeric material would not normally degrade. The combination of geotextile and granular materials in a composite filter in critical applications is thus proposed, in particular where thin cores or high hydraulic gradients may be expected as well as in applications where marginally suitable granular filter material is available, and where the permeating fluid has a detrimental effect on filter systems.

7. CONCLUSIONS

ICOLD Bulletin 55 recommends that geotextiles not be used as critical filters in dams. This is due to the nature of their being thin and easily damaged, as well as the questions of durability, and in applications where they cannot be reached for replacement they are considered too high a risk for sole defence against piping.

However, geotextile filters significantly reduce the risk of contamination of granular drainage media and thus allow for thinner drains due to their mechanism of filtration. It is thus recommended that while geotextiles can be selected for use in non-critical applications such as the outside of embankment dams under rip-rap etc., in addition, their use as adjuncts is advantageous in critical applications. Based on filter criteria and compatibility testing, nonwoven type geotextiles should be used in conjunction with designed granular filters as composite filter systems to reduce the thickness and hence cost thereof, and so reduce the risk of sustaining an open crack in the granular filter material, and to provide added protection of drainage provisions upon settlement.

It should also be recognized that due to the tensile resistance of a geotextile, they may readily span open cracks and thus induce early self-healing in the base soil, particularly where marginal granular filters are used.

For the purposes of this study, the substantial use of geotextiles in tailings storage facilities has been omitted.

In closing, environmental considerations also need to be considered. Simply put, the results of a major recent study show that *"A filter using a geosynthetic layer causes lower impacts compared to a conventional gravel based filter layer with regard to all impact category indicators investigated. For all indicators the filter with geosynthetics causes less than 25 % of the impacts of a conventional gravel based filter."* (Swiss Federal Institute of Technology, 2011)

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