Geosynthetics Enable Safe Drinking Water in Developing Countries

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ABSTRACT: "Safe drinking water for all" has been a prime goal for responsible government since Man first formed social groupings. As a State ambition this aspiration should override other infrastructural considerations, for a Nation without safe drinking water will be a debilitated people plagued by disease. It is an unfortunate truism that conventional concrete water storage reservoirs are expensive and the cost of building them is a restricting factor in a developing society's efforts to provide potable water for its people. Geosynthetics, represented by geomembranes, can provide water storage structures whose low cost in comparison to conventional concrete containments enable a greater number of reservoirs to be built for a given capital outlay. Membrane-Lined and Covered Reservoirs (MLCR), the subject of this paper, provide safe drinking water storage without compromising "First-World" requirements for durability, sanitary requirements and ease of operation.

1 INTRODUCTION

Ideally, an MLCR is a ground-level constructed earth impoundment, lined and covered with geomembranes. Other geosynthetics (typically geotextiles, geospacers and geopipes) provide a supporting role in the drainage and soil stabilisation components of the design. By the use of these lightweight, easily transportable and rapidly-deployed construction materials, significant cost savings are achieved over the use of concrete or steel structures, particularly where the reservoir site is remote and the transportation of conventional construction materials contributes significantly to the cost of the final structure.

2 MLCR DESIGN COMPONENTS

Experience in Southern Africa has shown that almost without exception, the most economical structural component of an MLCR is a balanced cut-to-fill engineered earth embankment. If the site is very rocky a combination rockfill/earthfill embankment structure may sometimes prove economical, utilising the excavated in-situ rock as the core of the embankment. Such a structure would also utilise a geotextile as the separating medium between the rockfill core and the earthfill embankment. Where (e.g. on rocky hills) use of engineered fills is not economical, a non-water retaining quality concrete shell can be used for supporting the linings. This type of design shows savings on both concrete and reinforcing steel. This paper will not go into the basic design of these earth or concrete structures as they are designed and constructed to conventional civil engineering codes of practise.

2.1 The containment lining

In Southern Africa, in the construction of over fifty reservoirs varying in size from 200m^3 to 125 M*l* stored volume (Davies, 1992), the containment lining has usually been a 1,0 to 1,5mm thick High Density Polyethylene (HDPE) of the type developed at the end of 1940 by Professor Karl Ziegler, who was then Director of the Max Planck Institute for Carbon Research based in Mülheim, Germany. (Bäumler, E. 1968). This is produced in South Africa from coal-derived Ethylene which is polymerised via the Hoechst Ziegler-Natta® process.

The HDPE lining usually overlies a minimum of a 270 g/m^2 non-woven needle punched continuous filament geotextile. This serves both as an anti-puncture shield between the lining and the underlying soil and also as a drainage layer to convey any possible leakage from the liner or groundwater seepage to the collector drain system which usually underlies the containment lining in these designs. The lining and the geotextile layer are usually anchored together at the top of the embankment by means of a metal angle bolted to a concrete perimeter beam.

2.2 The cover lining

The first small (⟩10M*l*) MLCR structures built in Southern Africa in the late 1960's made use of Isoprene Isobutylene Rubber (IIR) for the floating cover. These performed reasonably well but it was found that the durability of fully exposed IIR covers was not much greater than ten years under the local harsh weathering conditions (Ultraviolet radiation of ± 30 MJ/m^2) and only a couple were built using this material.

In 1985, the first major MLCR was built in Southern Africa. This was the 60 M*l* "Witbank" reservoir for the town council of Witbank in the Transvaal Province of South Africa. The town council's acceptance of the unconventional bid was a courageous step then, as not only was this to be the first major MLCR in Africa, but it was also not the lowest bid, as is shown in the tender prices given below:

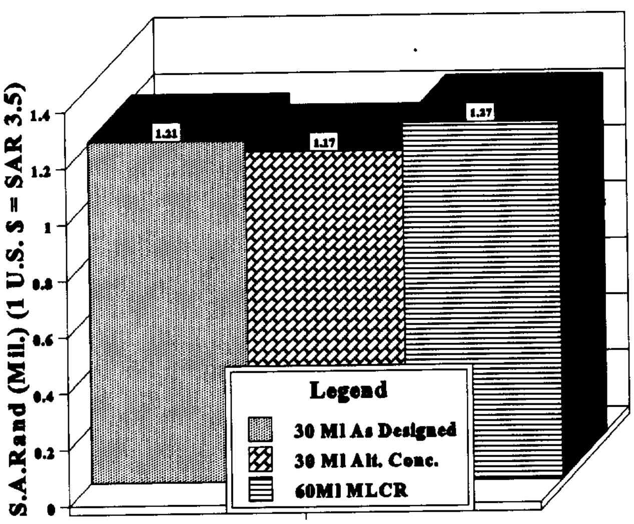

Fig. 1 Tender prices (1984) for the 30M*l* reservoir at Witbank, South Africa (after Turner and Davies, 1991).

From these prices it can be seen that in this instance a 60 M*l* MLCR reservoir was offered and accepted at a tender price of just over the cost of the 30 M*l* conventional flat-roof-on-columns concrete reservoir originally designed for this site.

The material used for the cover of this reservoir was 1,14mm 5-ply 16 x 8 leno weave 140 x 250 denier scrim-reinforced Chlorosulphonated Polyethylene (CSPE{R}) originally developed by Du Pont and imported from America. This material is not made in Southern Africa and the inconvenient procedures involved in importing it later led to the development of the "composite cover".

2.3 Development of the composite cover

A local 1mm thick Elastomeric Polyolefin Alloy (EPA) based on HDPE had been developed in 1979. This material has now been used for nearly all floating covers built in Southern Africa since 1986 (Davies P. and Meyer, P. 1990), at a considerable cost saving over the imported CSPE(R). This material is used for those areas of the cover that rise and fall in a single plane. Where multiplane folding of the cover is required (e.g. in the rainwater channels and the corners of the structure) CSPE(R) or Very Low Density Polyethylene (VLDPE) is used and is attached to the HDPE portion of the cover by means of a patented mechanical joint in the case of CSPE(R) or a welded joint in the case of VLDPE.

The development of the composite cover has enabled MLCR's to remain competitive in the face of a drastic devaluation of the South African Rand against most of the world's major currencies since 1984. How effective this move has been is demonstrated in the following table of tender prices for another 30 M*l* reservoir:

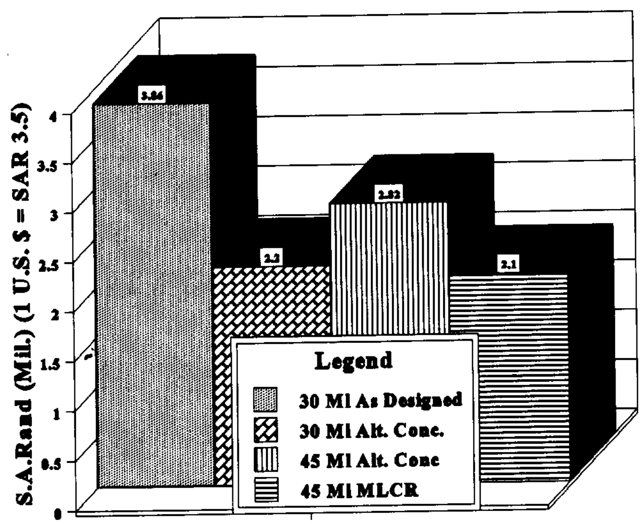

Fig. 2 Tender prices (1990) for the 30Ml reservoir at Vosloorus, South Africa (*The Civil Engineering Contractor, May 1991)*.

The as-designed reservoir featured above was of a conventional flat-roof-on-columns type and the alternative concrete designs were for the Freyssinet patent wire-wound / shotcrete wall / dome-roof construction. This is a very cost-effective (but controversial) design and it is interesting to note that a 45 M*l* composite cover design MLCR could still be offered at a 4,5% lower cost than a 30 M*l* reservoir of the Freyssinet type. The 45 M*l* composite cover MLCR showed a 25% advantage over the cost of a 45 M*l* Freyssinet offer. It is interesting too, to see how inflation has taken its toll in South Africa:

The 30 M*l* "Witbank" conventionally- designed concrete reservoir was priced at SAR 1,21 million in 1984. (Fig.1)

Only six years later the price for the same volume and basic design of structure was SAR 3.86 million (Fig.2) - a 219% increase in only six years.

3) WHY CONVENTIONAL CONCRETE CONSTRUCTION TECHNIQUES ARE EXPENSIVE

3.1 Cost of RC Materials

Bulk storage reservoirs are commonly built of Reinforced Concrete (RC), the basic constituents of which are: suitable sand; crushed stone; cement and reinforcing steel. It is a fortunate developing country which has a local manufacturing facility for all of these and the most expensive constituents, cement and steel, frequently have to be imported with concomitant foreign exchange penalties.

3.2 Cost of Transport of RC Materials

Unless a reservoir is to be built in the immediate vicinity of a plant producing sand and stone aggregates, the cost of transporting these materials long distances very soon exceeds the actual cost of the individual materials. Crushing plants are usually only to be found near major centres and this makes providing concrete in rural areas an exceptionally expensive exercise.

This also applies to cement and steel. Both are heavy materials requiring expensive transport facilities to effect delivery to remote sites. In countries with limitations on fuel availability the problems lie not just in the fuel cost but also in the drain on resources such heavy transport requirements represent.

3.3 Cost of Placing RC Materials

Using RC to construct anything except the smallest of reservoirs requires a substantial plant presence on site. Concrete mixers; dumpers; cranes; concrete vibrators and suchlike are usually imported plant items, the fuel to operate and amortisation of capital cost of which has to be added to the cost of placing concrete.

3.4 Cost of Volume of RC Reservoir Materials

A reservoir structure usually comprises four clearly identifiable containment components:

1) Wall (Circular or rectangular)
2) Floor
3) Roof (Flat slab on columns or circular domed)
4) Waterproof jointing between these concrete elements

For clarity, a brief look at these elements is in order:

3.4.1 Wall

A concrete wall usually rests on a heavy RC foundation which transmits the mass of the structure and its contents to the underlying formation. Its purpose is to contain the water and support the roof structure. Due to the heavy loads the wall has to cope with it is rarely less than 250-300mm thick.

3.4.2 Floor

The floor normally consists of articulated RC slabs which are rarely less than 100-200mm thick as they have to transmit the load of the contained water to the underlying formation and resist cracking forces brought about by small residual settlement movements when the reservoir is filled.

3.4.3 Roof

The roof concrete, whatever the design, is rarely thinner than 150mm. If the roof is flat then concrete columns on footings are required to prop it up. A domed roof escapes the need for props but requires a greater surface area of concrete (and more expensive, complex temporary support shuttering) to cover a given volume of water.

A brief look at even state-of-the-art concrete reservoir designs will show that on average about one third of the total materials used are required to form the roof of such structures, whether the roof is a flat slab on columns, or a domed design and all this is just to keep the water clean.

3.4.4 Jointing

As concrete is inherently a brittle construction medium, all these components of a concrete reservoir have to be joined by flexomeric joint sealants and water bars to accept the differential movements caused by fluctuating loads applied during the filling and emptying cycles of the structure (as well as thermal movements). It is usually these flexomeric components (the available products whose qualities vary widely) which require regular maintenance in order to keep the reservoir structure watertight. Failure to provide regular maintenance frequently results in joint failure.

Although concrete has traditionally been the material of choice for reservoir construction, its required massive nature has lead to its being a high-cost solution to the problem of water storage. It seems that conservatism and inertia in the field of civil engineering thinking has kept it in the forefront for so long, for logically, it really is not the ideal low-cost material for most potable water storage applications. A look at the reasons why geomembranes have not taken over from concrete, reveals the following:

4 CONSTRAINTS ON THE USE OF MLCR TECHNOLOGY

4.1) Lack of Education in Polymer Technology

The Southern African use of geomembranes in particular is driven primarily by installation contractors and a very few consulting and government engineers. These bodies are responsible for most innovations in the use of these materials and the academics and manufacturers of polymers and geomembrane sheet materials contribute almost nothing to the state of the art in South Africa. This is very different to the situation in Europe and America where a more vibrant market is very much driven by the academic, consulting and manufacturing sectors.

Southern African civil engineers unfortunately receive little instruction in geosynthetics technology at university level. At present, undergraduate civil engineers receive only the most perfunctory of introductions to the discipline and only post-graduate students enrolled on specialist courses are offered any in-depth insight into geosynthetic theory and practise (these courses are not offered on a regular basis.) Designers well versed in the capabilities of "conventional" construction materials such as concrete and soil, or steel and timber, are thus understandably uncomfortable with construction materials whose behavioural characteristics are best understood by those with a knowledge of polymer technology.

4.2) Perceptions of Vulnerability to Mechanical Damage

Geomembranes are relatively fragile construction materials when compared to concrete and most design engineers are justifiably concerned about the possibilities of mechanical damage to the linings due to outside influences such as vandalism and theft. Experience has shown however that such damage, whilst possible, only rarely occurs. Furthermore, the cost savings associated with geomembranes as construction materials are usually of such a magnitude that effective security measures can be put into place without losing the cost benefits that most MLCR structures offer.

Where mechanical damage to the liner has occurred, this has usually been confined to the cover lining and has invariably been attributable to a complete lack of attention to security by the owner of the facility. In one instance where a South African cover was vandalised, the site security gates had been left not just unlocked, but wide open, from the date of commissioning of the structure. Despite this lack of care, vandalism occurred only two years after the structure had been taken into service.

It must be appreciated that MLCR structures are different to concrete structures, which are not easily vandalised to the point that their function is affected. Designers and client bodies should appreciate that part of the large cost savings realised should be invested in proper site security measures. It is here that research should be initiated, to achieve maximum security at least cost and negative aesthetic impact.

5) CONCLUSIONS

Membrane lined and covered potable water reservoirs are slowly becoming as much a part of the Southern African construction scene as they are overseas and the use of this design approach is being practised by more and more consulting engineers. Undue conservatism on the part of specifiers has however prevented the greater use of this type of structure, to the detriment of a substantial population desperate for safe water.

Very substantial cost savings over conventional concrete reservoir designs can be realised by the use of MLCR technology. The larger the reservoir, the greater the cost saving. This type of structure should be considered by all specifiers when water-retaining structures are being considered.

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