SA Water

SOUTH AUSTRALIAN WATER CORPORATION

TG 10f

TECHNICAL GUIDELINE

GENERAL TECHNICAL INFORMATION FOR GEOTECHNICAL DESIGN

~ Part F ~
Lined Storages

Issued by: Manager Engineering

Issue Date: 10 January 2007

Government of South Australia

No Changes Required In the January 2007 Edition

The following lists the major changes to the November 2004 edition of TG 10f:

1. Nil

Contents

Tables & Figures

Referenced Documents

Cooltong Basin Draft Report

Section 1: Scope

Section 2: Lined Earth Storages – Design Principles

Lined earth storages are currently undergoing a period of popularity in SA Water. This is mainly because they appear to be an economical way of meeting the relatively recent need (in SA) to store large volumes of treated water out of contact with the ground and covered from the air. Generally they are, but they are not appropriate for all sites, and even for sites where they are appropriate certain basic design constraints should be observed if their full benefits are to be realised and their shortcomings avoided.

Some of the basic design constraints have been pushed to or beyond their limits on recently designed/constructed storages. This has resulted in costly delays and rectification work, embarrassingly inelegant engineering solutions, or a difficult to maintain finished structure.

The purpose of these notes is to provide designers with a checklist of the basic design principles for lined earth storages so that such pitfalls can be avoided in future.

Table 2.1 - Basic Design Constraints of Lined Earth Storage VS Aboveground Tank.

Conditions that Favour a Lined Earth Storage	**Conditions that Favour an Aboveground Tank**
Large storage volume (> 20 ML)	Smaller storage volume (< 20 ML)
Deep soil profile – no rock in the excavation *	Rock foundation at shallow depth
Large site – no boundary constraints	Restricted or oddly shaped site
Flat site with balanced cut and fill	Steep slopes acceptable
Internal slopes can be flatter than 1V:4H *	Internal slopes of a LES on the site would have had to be steeper than 1V:3H *
External slopes can be flatter than 1V:5H *	External slopes of a LES on the site would have had to be steeper than 1V:4H *
Shallow depth / large area of storage desirable	Tall tank required (surge tank / water tower)
Excavator can reach all of slope from floor/top	LES would have had to be too deep for an excavator to reach all of the slope from floor/top
Floating cover is acceptable	Fixed roof is desirable or needed
Few penetrations (eg I/O sumps) through liner	Many penetrations (eg column bases) needed

No penetrations on slopes	Penetrations (eg column bases) would be required on the slopes
Design TWL at about site natural surface level	Design TWL well above site natural surface
No bushfire and/or no vandal risk	Significant bushfire and/or vandal risk present
Infrequent cleaning required	Frequent cleaning required
Low visual impact desired (low-angle outer slopes can be landscaped to look "natural")	Visual impact less of an issue (or because of small size the tank can be screened with trees)

2.1 General Design Notes

Table 2.2 - General Design Notes.

Slopes 1V:2H (26° or 50%) Cannot be safely walked on irrespective of their surface finish. Cannot be worked on by construction plant or rollers of any kind. The slope itself may be unstable in some soils or jointed rocks. Ordinary sand (with an angle of friction of say 30°) would be on the verge of stability on this slope – so only stabilised materials could be used to smooth the slope or as a liner-bedding layer, and even these would be difficult to place and compact. It may be difficult to bond/interlock a stabilised material to a slope this steep – it may be necessary to cut key pockets, drape a geogrid down the slope, or use a "structural" liner-bedding layer (eg reinforced shotcrete).
Slopes 1V:3H (18° or 33%) Can just be safely walked on if they have a non-slip finish (eg not a wet liner). Can be climbed by some tracked plant if the surface is stable and not slippery. Only towed rollers can be used (not rigid chassis). Ordinary sand (with an angle of friction of say 30°) would have a factor of safety of only 1.7 on this slope. Sand would be easily displaced during construction, and both sand and rubble may become unstable if saturated during operation – it may still be desirable to use stabilised material to smooth the slope or as a liner-bedding layer.
Slopes 1V:4H (14° or 25%) Can be easily walked up. Can be worked on by most construction plant across the slope as well as up and down. If the surface is stable and not slippery they can be driven up in a 2WD vehicle. Rigid chassis rollers are allowed. Sand or rubble may be used as the smoothing or liner-bedding layer. (The FS for sand with an angle of friction of 30° would be 2.3.)
Slopes 1V:5H (11° or 20%) Are an appropriate outer slope for a storage. They have a "natural" landscaped appearance. They can be readily walked up or driven on in a 2WD vehicle. They are relatively resistant to erosion by rain or irrigation runoff, and can be mown by most ride-on mowers.

Slope Finish
All pockets/voids in the floor/slopes must be filled and bumps flattened. Excavations in the floor/slopes should be backfilled either with material with a similar compressibility to the surrounding material (eg concrete if in rock), and/or a gradual transition detail incorporated.
Liner Bedding Layer If the floor and/or slopes cannot be trimmed and/or rolled to an acceptably smooth finish, then a liner bedding layer may be required. This may consist of compacted sand or rubble fill, but the stability of such materials on saturation followed by "rapid drawdown" in the storage should be considered. An ideal material is cement-stabilised sand as it gives a smooth, tough, slip resistant, bedding layer that will also stabilise the surface beneath. Cement stabilised sand (CSS) is particularly effective at smoothing and locking together the surface of jointed rock cut slopes or rocky fills. If the CSS is made using very clean coarse sand / fine gravel (grit) and 8% cement, and if it is only lightly screeded (not compacted) into place, then not only will the liner bedding layer have good strength, but it will also be very permeable both across its thickness and down the slope. It will therefore act as an excellent underdrainage layer for the slopes and/or floor.
Underdrainage The design of all water storages should allow for the foundation to become saturated from leakage and/or external groundwater inflow. For lined earth storages an engineered underdrain system will generally be necessary – at least beneath the floor. (See liner bedding layer above.) The outlet should be brought to the surface so the discharge can be monitored.

This "Technical Note" was prepared by Ed Collingham, 18/12/2003
(Ex Principal Engineer Geotechnical)

Section 3: Examples of Lined Storages

An irrigation storage in the Clare Valley showing the prepared soil surface. A geotextile underlay is often used where the soil contains sharp rubble, but in this example there is none	Date Taken / /	**Photo 1**

The same storage as above about year later. Internal slopes are about 1 on 4. A low slope such as this makes it easy to compact the surface and to roll-out and weld the liner. It also reduces the tendency of the liner to creep down the slope.	Date Taken / /	**Photo 2**

Another lined irrigation water storage in the Clare Valley. The internal slope on this one appears to be even flatter – about 1 on 5. There is no tension on these liners so the top edge is simply turned down into a shallow trench and backfilled.	Date Take / /	**Photo 3**

Another Clare valley irrigation water storage with a very flat internal slope. Note that on this one there is almost zero width at the top of the embankment.	Date Taken/ /	**Photo 4**

The treated effluent storage at Christies Beach WWTP. Note the varying freeboard – instead of, say, cutting a bench at a fixed elevation, the liner was continued up the slope to the left until it was convenient to return it into the ground.	Date Taken / /	**Photo 5**

The treated effluent storage at Christies Beach WWTP. The fence has a concrete footing/path, but the liner is still simply returned into a backfilled trench. The aggregate is probably just a surface finish rather than the backfill. It is usual to try to avoid having sharp aggregates anywhere near a liner.	Date Taken / /	**Photo 6**

This “Technical Note” was prepared by Ed Collingham, 31/01/2003
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Section 4: Generic Specifications for Construction of a Clay Liner – Sludge Lagoons

4.1 Clay Lining the Sludge Lagoons

The clay liner shall cover the whole floor and all sides of the sludge lagoons up to the top of the embankment fill (i.e. to the underside of the paving). The designers should determine and confirm the required thickness of the liner. However, the total thickness of the clay liner shall not be less than 300mm.

The following method shall be used to ensure that permeability of the clay liner is ≤ 1x10-9 m/sec.

- Percentage of fine shall not be less than 25%
- The clay shall be non-dispersive of low/moderate plasticity
- The clay shall not contain more than 20% of fine/medium gravel
- The clay shall be placed in layers not exceeding 150 mm loose thickness. The placing and compaction procedures shall be carried out in such a way as to prevent the drying out of the clay.
- Each layer shall be compacted to not less than 98% of Standard Maximum Dry Density.
- Prior to placing the clay, the moisture content of the clay shall be within 1% Dry to 3% Wet of Standard Optimum Moisture Content.
- Before placing the new lift, surface of the previously compacted layer shall be scarified to a depth of at least 50mm. If the surface dried out and/or cracked, it shall be ripped or disc-ploughed to at least 50mm below the depth of drying or cracking then watered and mixed.
- Each layer shall be placed and compacted over the internal surface of the lagoon before any part of the next layer is started.

4.2 Clay Liner Protection

The clay liner shall be permanently protected from mechanical damage and drying-out. Three options of liner protection could be used. Minimum thickness of the clay liner protection shall not be less than 250 mm. These options are:

4.3 Sand/Gravel Cover

The sand/gravel layer shall not be susceptible to erosion by water flow. The sand/gravel cover shall be placed in one layer. The sand/gravel shall be compacted to not less than 92% of Standard Maximum Dry Density.

4.4 Clay Cover

As per Section 1.1, with exception of the following.

- The clay cover shall be placed in one layer.
- Compaction ratio shall not be less than 92%.

4.5 Cement Treated Quarry Rubble (CTQR) Cover

This probably would need a synthetic membrane between the clay liner and the CTQR.

Allow for the supply, placement and compaction of SPM20C4, as per Transport SA specifications. Place and compact the CTQR within 2 hours of delivery to site. Place and compact the CTQR to 92% of Standard Maximum Dry Density.

This “Technical Note” was prepared by Ed Collingham, 22/12/2003
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Section 5: Notes on the Control of Infiltration from Lagoons

Design of Disposal Basins – General Principals
(Extract from Cooltong Basin Draft Report)

A proportion of the water discharged into a disposal basin will be lost by infiltration. The task of the designer is, generally, to minimise the infiltration and to predict its impacts such that the acceptability of operating the basin can be assessed.

The minimisation of infiltration can be achieved by selecting a site underlain by an effective natural aquitard. Infiltration will also be limited where a basin is close to or below the pre-existing watertable and distant from any groundwater discharge point such as a river.

The natural attributes of a site can be enhanced by placing a synthetic liner on the floor of the basin (expensive), or by surrounding it with ditches, drains, wellpoints or bores and returning the intercepted infiltration to the basin.

Generic Specification Clause for the DESIGN of Infiltration Loss Control Systems for Lagoons (Taken From Geotechnical Files)

The designer shall ensure that the rate of infiltration loss from any lagoon to the local groundwater is less than ….. m/s.

Acceptable designs might include any or a combination of the following:

- Reliance on undisturbed natural materials in the floor and side slopes of a lagoon whose properties, lateral extent and depth have been proven by investigation.

- Reliance on a low hydraulic gradient between the lagoon top water level and any receiving surface waters or groundwater.

- The construction of surface or sub-surface interceptor drains with pumping back to the lagoons.

- The construction of a compacted natural clay liner beneath the floor and side slopes of the lagoon (including an overlay of sand or gravel to ballast and mechanically protect the clay and prevent it drying out).

- Fill embankments whose inside face consists of 2 m (measured horizontally) of compacted clay soil.

- A geosynthetic clay liner system such as Bentofix™ or Claymax™ (including an overlay of sand, gravel, quarry rubble or cement treated quarry rubble to ballast and mechanically protect the clay and prevent it drying out).

- An HDPE or similar geomembrane liner system.

Where there is more than one lagoon in a group, and a liner system is to be used, each lagoon may be lined individually, or the liner may be placed under the whole area of the lagoons and the dividing and perimeter embankments built over it.

The design of any liner system shall allow the sludge to be removed from the lagoons using wheeled plant without damage occurring to the liner.

Sample Spec for the CONSTRUCTION of a NATURAL CLAY liner to RESTRICT infiltration into the floor of a WATER FILTRATION PLANT sludge lagoon.

This is an extract from specification for the Mt Pleasant WFP. Note that the supernatant from WFP sludge is almost potable (unlike the supernatant from WWTP sludge) and so it was agreed at the time that it was sufficient merely to restrict the rate of infiltration rather than try to "prevent" it totally – provided that the alum flock was retained. In the end the lagoon floors were finished with a layer of compacted 20 mm quarry rubble stabilised with 6% cement. This dual lining provided an excellent seal as well as an excellent working surface.

5.1 Clay Lining the Sludge Lagoons

The clay liner shall cover the whole floor and all sides of the sludge lagoons up to the top of the embankment fill (ie to the underside of the paving.

The total thickness of the clay liner shall be 300 mm. The tolerance on the thickness of the clay liner shall be minus 0 mm to plus 50 mm.

The following METHOD shall be used to construct the clay liner. Performance criteria (eg field density testing) will NOT be used for quality control. The intent of the method is to achieve the required low-permeability by ensuring the destruction and remoulding of clods throughout the full thickness of each layer, and good bonding between layers.

The moisture content of the clay shall be adjusted to be between 2% and 6% wet of optimum moisture content (standard compaction) PRIOR TO PLACING.

The clay shall be placed in layers not exceeding 150 mm LOOSE thickness.

Each layer shall be compacted by six passes of a sheepsfoot roller approved by the Superintendent's Representative.

The placing and compaction procedures shall be carried out in such a way as to prevent the drying out of the clay.

Each layer shall be placed and compacted over the full internal surface of the lagoon before any part of the next layer is started.

5.2 Sand/Gravel Ballast on Clay Lining

The clay liner shall be permanently protected from mechanical damage and drying-out, and also ballasted, by a layer of sand/gravel.

The total thickness of the sand/gravel layer over the clay liner shall be 400 mm. The tolerance on the thickness of the sand/gravel layer shall be minus 0 mm to plus 50 mm. No payment will be made for thicknesses greater than the specified tolerance.

The sand/gravel ballast shall be placed in layers not exceeding 150 mm thick when compacted, and each layer compacted separately to not less than 95% of standard maximum dry density.

5.3 Riprap for Sludge Lagoons

The internal faces of the sludge lagoons shall be protected from wave erosion by a 100 mm thick layer of riprap.

The riprap shall have a grading equivalent to Department of Transport Standard Specification PM3 (BALLAST, 65 mm) unless otherwise approved by the by the Superintendent's Representative.

The tolerance on the thickness of the sand/gravel layer shall be minus 0 mm to plus 50 mm. No payment will be made for thicknesses greater than the specified tolerance.

<u>Sample Spec for the CONSTRUCTION of a Geosynthetic Clay Liner to RESTRICT infiltration into the floor of a WATER FILTRATION PLANT sludge lagoon.</u>

This is an extract from specification for the Mt Pleasant WFP. Note that the supernatant from WFP sludge is almost potable (unlike the supernatant from WWTP sludge) and so it was agreed at the time that it was sufficient merely to restrict the rate of infiltration rather than try to "prevent" it totally – provided that the alum flock was retained. In the end the lagoon floors were finished with a layer of compacted 20 mm quarry rubble stabilised with 6% cement. This dual lining provided an excellent seal as well as an excellent working surface.

5.4 Geosynthetic Clay Liner with CTQR overlay

Additional Excavation

For those parts of the lagoons in excavation, excavate an additional 310 mm (measured perpendicularly) beyond the finished surface.

Reduction in Fill

For those parts of the lagoons in embankment, finish the embankment fill 310 mm (measured perpendicularly) short of the finished surface.

Preparation of the Cut and Fill Surfaces

Compact cut and filled surfaces to 95% of standard MDD to a depth of 150 mm.

Geosynthetic Clay Liner Specification

Allow for the supply and placement of one layer of geosynthetic clay liner over the floor and all sloping sides of the lagoons.

Note: A geosynthetic clay liner consists of a layer of bentonite clay powder sandwiched between two layers of geotextile filter fabric. It is about 5 mm thick (when dry) and is supplied in rolls. A geosynthetic clay liner can be laid directly on a rough surface (stones protruding up to 20 mm), and needs no special laying skills or jointing – it is merely lapped.

The cost of geosynthetic clay liner is currently about $7.50 per square metre. (Based on Bentofix supplied by Geofabrics Australia, Rod Fyfe 8293 1306.)

CTQR Overlay Specification

As with a natural clay liner, the geosynthetic clay liner needs to be surcharge loaded and protected from drying-out and mechanical damage by an overlay layer.

Allow for the supply, placement and compaction of a 300 mm thick layer of 4% cement treated quarry rubble (CTQR). Place and compact the CTQR within 2 hours of delivery to site.

Place and compact the CTQR to 96% of Modified maximum dry density in layers not exceeding 150 mm compacted thickness.

Allow for ten field density tests.

5.5 Comment on Draft EPA Requirements for Limiting Infiltration from Wastewater Lagoons

(Ex Geotechnical Files)

The draft specifies that the rate of loss of pond depth by infiltration must not exceed 0.1 mm/d. This rate is equivalent to about $1x10^{-9}$ m/s. The implications of this rate of loss for a lagoon lined with natural clay are illustrated below.

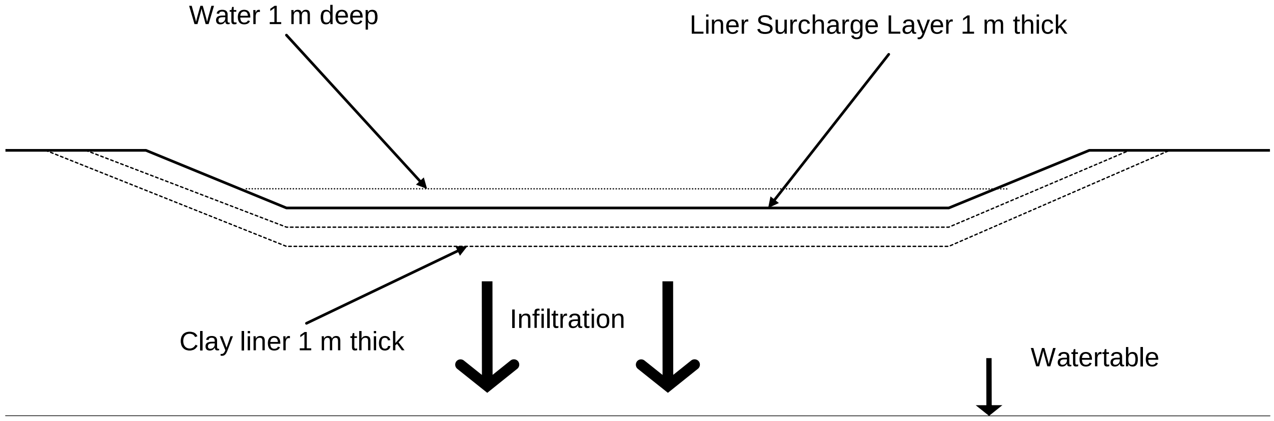

Figure 5. 1 - Diagram of Infiltration through Liner.

In the diagram above the natural clay liner is a generous 1 metre thick and the hydraulic head on its upper surface is only 2 metres. The watertable is some distance below the underside of the liner. The hydraulic gradient through the natural clay liner would therefore be only 3 (metres per metre).

To keep infiltration below the specified maximum rate of $1x10^{-9}$ m/s the natural clay liner would need to have a permeability less than 1/3 x ($1x10^{-9}$) m/s or 0.3 x 0^{-9} m/s.

In practise it is difficult to construct a compacted natural clay liner with permeability much lower than 5 x 10^{-9} m/s. This is 15 times more permeable than the EPA draft regulations in effect specify.

The proposed regulations therefore effectively exclude the use of natural clay liners in wastewater lagoons. Is this what is intended?

This “Technical Note” was prepared by Ed Collingham, 18/12/2003
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