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Low Permeability Liner Construction Difficulties

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Summary During construction of low permeability liners at various sites within Victoria and South Australia a number of construction difficulties have been observed by the author. Various constraints on the projects included physical restrictions, climatic conditions and material properties.

The aim of this paper is to outline several difficulties encountered during construction of low permeability liners and provide case study examples of some practical solutions.

The emphasis will be on three commonly used liner materials - clay, geomembrane and slimes. In several cases the issues were site specific relating to physical conditions encountered. However, the majority of construction problems encountered could be traced back to problems associated with moisture level, bearing capacity, subgrade strength and material properties.

1. INTRODUCTION

Low permeability liners are constructed for a variety of different uses and are generally designed to either contain material within a storage area and prevent migration beyond the site boundary, or as a capping layer to isolate the storage area and prevent water infiltration through the liner. Low permeability liners are commonly used in landfills and by mines and heavy industry which generate waste product requiring temporary or permanent storage. Storage facilities are typically lined and capped to prevent the migration of potentially contaminated soil, liquid or gases beyond the storage area.

The type of liner used varies according to the characteristics of the site, climate, location, materials available, level of liner permeability required, site specific uses, and ultimately the cost to construct. The three most commonly used liner materials are clay, geomembrane and slimes. Composite liners combining different materials are also in use.

Some sites have adequate supplies of clay or slimes are available as a by-product from an extraction process. However, some sites may require a geomembrane liner due to a lack of suitable alternative material or because of the level of permeability required.

Clay liner construction difficulties are generally associated with either;

1. moisture loss resulting in cracking of the clay,
2. damage to the clay by construction traffic,
3. material properties which lead to problems achieving compaction and/or permeability of the liner,
4. shear failure of the clay, and
5. the strength of the underlying subgrade.

The problems in installing geomembrane liners are usually associated with weather conditions and the strength and finish of the underlying subgrade layer.

Slimes are a saturated fine grained soil, generally clay, silt and sometimes with sand, which can be used for the construction of a low permeability liner. Slime liners provide construction difficulties due to a low shear strength and moisture loss causing settlement.

Construction difficulties encountered with clay, geomembrane and slimes low permeability liners are discussed in more detail in the following sections.

2. CLAY LINER CONSTRUCTION

The specification of clay liners varies depending upon the specifics of the particular project. A typical landfill site in Victoria requires a liner with a coefficient of permeability of about 1×10^{-9} m/s. This can generally be achieved by compacting a predominantly clayey material to achieve a minimum dry density ratio (AS 1289.5.4.1) of 95% Standard, moisture conditioned within the range of 0% to +3% of the Standard Optimum Moisture Content (SOMC) in accordance with AS1289.2.1.1.

To achieve the permeability requirements of the clay liner typically the clay needs to be moisture conditioned to be wet of SOMC. Subsequently, depending upon the material properties, the reconditioned clay generally has a higher moisture content than its natural moisture level and has a lower strength than when compacted dry of SOMC.

Several construction difficulties emerge when handling clay soils which require re-conditioning to be wet of SOMC. In dry, hard clay soils, particularly high plasticity clays which have a natural moisture content very much lower than SOMC (as is typical of much of the arid clays found in South Australia), the action of moisture conditioning clays becomes difficult. The clay tends to break into 'clods' which become saturated on the surface but the water does not immediately penetrate to provide the even moisture profile required. As a result the clay becomes extremely slippery and can become unworkable for normal construction plant. Subsequent compaction of such a clay layer may appear sufficient on the surface of the layer. However, inspection of the layer can often reveal a matrix of clods of dry, low density clay which have not been sufficiently remoulded resulting in a high permeability layer. Reworking the material can be a time-consuming and costly exercise.

Alternatively once clay has been adequately remoulded to wet of the SOMC any significant drying of the clays results in typical shrinkage cracking of the surface.

Construction traffic can cause problems with clay soils which have been remoulded to a moisture content wet of SOMC. Clay liners generally require several layers of compacted clay to complete the liner. In large scale production the liner material is bulk hauled with heavy machinery requiring fully laden highway trucks, dump trucks, scrapers or similar to travel over the preceding layer in order to place the material for the next layer. The results of continuous trafficking over clay liners is that pore water pressures can develop and the clay liner can deform and fail in bearing capacity and shear failure.

The author has observed several examples of shear failure of clay liners particularly in high plasticity clays located in South Australia. Shear failures were observed in the clay on either side of the wheel ruts observed on haul roads. The ruts were created by dump trucks travelling over clay which had been compacted to a minimum dry density ratio of 95% Standard at moisture contents wet of SOMC. Attempts were made to restore the affected areas by compaction with pad foot rollers. The top 100mm of the layer had been remoulded sufficiently within the 'footprint' of the 'pads' of the pad foot roller and testing proved that the density and moisture content limits had been achieved throughout the full layer. However, close inspection of the clay revealed shear failure planes throughout the underlying bottom half of the layer. Large sections of the clay could be peeled off to reveal slickensided semi circular shaped clay faces showing clear evidence of widespread shear failure of the clay. Despite the surface appearing suitable and the density testing meeting the technical specification the clay layer was rejected due to the potential for the shear planes to act as high permeability faults within the liner.

Another common problem is the effect the quality of the subgrade or underlying layer has on the construction of clay liners. Low strength subgrades typically result in difficulty in reaching the compaction levels required. If the subgrade does not offer sufficient resistance then no amount of compactive effort will achieve the required density levels in the clay liner. If the clay liner is overworked the potential for contaminating the clay liner by 'pumping' the subgrade material into the uncompacted clay is also significant, particularly if the subgrade is saturated. Various methods for treating subgrades include removal of isolated trouble spots, bridging the subgrade with an intermediate soil layer and various forms of geotextile which act to stabilise the subgrade.

The author has observed various examples of unstable subgrades generally associated with highly compressible and/or saturated soils, such as water courses which have been diverted, and compaction over fill material.

Examples include landfill sites where the compacted wastes were particularly spongy and uneven and required a clay capping layer. An example of a poor subgrade which comprised highly compressible wood shavings is discussed in more detail in Section 5 - Case Studies.

3. GEOMEMBRANE LINER CONSTRUCTION

Geomembrane liners are becoming increasingly popular in areas where there is a shortage of suitable clay deposits to construct clay liners. Geomembrane liners have various forms. However, for the purposes of this paper the discussion will be limited to one of the most commonly used forms of membrane, the High Density Poly Ethylene (HDPE) liner.

HDPE liner used in construction observed by the author is generally 1.5mm thick although different thicknesses are available. During construction of the geomembrane liner, panels of HDPE are spread over the subgrade and subsequently welded together with specialised equipment to provide a seam which is stronger than the parent material. The panels typically come in large rolls approximately 6 to 7 metres wide and 110 metres long.

Changes in ambient temperatures can cause the HDPE panels to expand or contract considerably over such a long section of panel. As a result wrinkles can easily develop in the panels and cause problems during welding of the seams. For example, if two panels are welded together where one panel is at a different temperature to another (say for example if a recently rolled panel is sitting adjacent to a panel which has been out in the heat all day) then once the panel temperature stabilises the two panels expand or contract by different amounts. Hence, stresses build up along the weld seam which can affect the soundness of the liner. Typically when this occurs one panel will appear even and well constructed while the adjoining panel will have a series of wrinkles emanating from the weld seam as the panel wants to expand to its original shape, but is restricted by the weld.

Expansion and contraction of the HDPE can also produce problems with the final liner if temperatures during construction are very much higher than normal operating temperatures for the HDPE liner. In such cases the liner contracts as temperatures drop and creates tension stresses within the liner. The author has observed an HDPE liner constructed within a lagoon with a flat base and edge walls sloping at 1V:3H with liner extending to the crest of the wall. Temperatures during construction of the liner were generally above 30 degrees C in the day during welding. Panels were secured at both ends in trenches and left overnight. During the night the temperature fell dramatically, causing the HDPE liner to contract by at least 1 to 2 metres laterally across the lagoon, causing the HDPE liner to lift away from the edge wall under the tension and create an air void at the base of the lagoon walls between the liner and the underlying subgrade. If left unchecked the liner would have sustained high tensile stresses once filled.

Another problem encountered with HDPE liner construction is the influence of wind displacing panels during construction and blowing dust over the panels. Dust can interfere with the welding process and create potential faults in the welds. Wind blowing over the top of a fully constructed liner can also cause an uplift effect which has been known to lift the HDPE liner off its subgrade and create large wrinkles across the liner.

Where significant, wrinkles in the liner must be removed so that the HDPE remains flat when loaded under working conditions. If left unchecked the wrinkle may fold on itself and create a crease in the HDPE and potentially weaken the liner.

The quality of the subgrade is another problem associated with the construction of HDPE liners. The surface needs to provide a firm unyielding foundation for the geomembrane with no sudden sharp or abrupt changes or break in grade, free of sharp objects, rocks, hollows, sticks, roots or debris of any kind. If any of these defects are found on the subgrade surface they have the potential to tear or rub the HDPE panels. This problem is particularly significant during construction and any unloaded phases of use when the liner is free to expand and contract with daily temperature changes. The panels are likely to move continuously over the debris causing higher potential for failure of the liner. An example of a problem with the subgrade surface quality and a practical solution is discussed further in Section 5 - Case Studies.

Heavy machinery used to place HDPE panels can often cause rutting in the subgrade surface. Ruts and wheel marks create sharp edges with the potential to deform the HDPE liner once loaded. Hence, particular care is required to maintain a smooth surface. Often the geomembrane is part of a composite system and is laid over the top of a clay liner. In these cases the subgrade is particularly susceptible to damage by machinery moving panels into position due to the high moisture content and low strength of the liner as previously discussed. As a result panels are quite often rolled out by hand to avoid these difficulties.

4. SLIMES LINER CONSTRUCTION

Slimes are saturated fine grained soils, (clays or silts, sometimes with fine sands or combinations of all three) produced as a by-product during wet processing from metallurgical or extraction industries. For example, the extraction of minerals from an ore body often creates vast quantities of saturated clay and silt which is generally spread out to facilitate evaporation of the liquor, leaving a highly compressible, high moisture content slimes.

Use of slimes in liner construction generally occurs where there is a significant cost advantage due to the availability of this material on or near the construction site. Due to a typically high moisture content and low strength, slimes are generally pumped or carted into position and then require a period of time to consolidate and allow excess liquid to evaporate.

Construction difficulties arise with slimes liners when the time for consolidation and evaporation of each layer is too long for suitable construction times. If layers are added without adequate time for consolidation then the potential for settlement problems is high.

Loads applied to slimes liners are also a major problem during construction. The slimes may have a sufficiently low permeability but also exhibit a low shear strength and bearing capacity and are unable to support the weight of product to be stored over the slimes liner or the live loads of construction vehicles. Further examples are discussed in Section 5 - Case Studies.

5. CASE STUDIES

5.1 Composite Clay / Geomembrane liner, South Australia

A composite clay / geomembrane liner was constructed in an arid area of South Australia. The construction process consisted of subgrade preparation, placing and compaction of a minimum 0.5m thick clay liner capable of achieving a coefficient of permeability of 1 x 10^{-9} m/s, overlain by a HDPE geomembrane 1.5mm thick. Construction occurred during extended periods of windy, hot weather with temperatures ranging up to 40 degrees C but typically 25 degrees C during the day and generally falling to 5 to 10 degrees overnight. The lagoon was designed to contain highly acidic liquor.

During construction of the clay liner particular care was needed to ensure that only non-calcareous clays were used for the liner. Calcareous clays containing calcium carbonate were found in abundance at the clay source. If a leak were to occur and acid came in contact with calcareous soils the carbonates would potentially react with the acid to form an acid-base reaction giving off gas and water as per the following equation:

$$(1)\ CO_3^- + 2H^+ \longrightarrow CO_2 + H_2O$$

If such a reaction were to occur the permeability of the clay liner would increase dramatically as the carbonates are converted to carbon dioxide and water, leaving voids in the liner. In addition, a build up of gas from acid attack of calcareous clays would be trapped beneath the HDPE liner and create a gas bubble underneath the liner. Hence, only non-calcareous clays were used during construction of the clay liner.

Due to the high rates of evaporation in the arid construction area there was a constant threat of water loss from the clay liner. The specification required a minimum dry density ratio of 95% Standard, moisture conditioned within the range of 0% to +3% of SOMC.

The Contractor used an RS500 rotary mixing machine to moisture condition and break down the dry, hard, high plasticity clays to ensure a homogenous clay layer was produced. The RS500 was observed to produce a remoulded clay layer without the problem of dry 'clods' of high permeability clay as discussed previously in Section 2 - Clay Liner Construction. The RS500 was also used to prevent desiccation and cracking of the clay liner due to moisture loss. After a layer was completed the following layer would be placed and conditioned including the top 50mm depth of the previous layer. Hence, the RS500 was able to remove any surface laminations, desiccated or dry soil which may have been on the surface of the first layer. After compacting the second layer testing was then undertaken on the first layer. Once passed, the process continued thereby ensuring that the clay met the specifications. The final layer was placed to a level approximately 150mm above the finished surface and cut back to level just prior to laying the HDPE geomembrane liner on top, thereby maintaining the integrity of the clay liner.

Another problem arose during construction due to the heavy traffic of fully laden dump trucks carting clay over conditioned clay layers. Shear failure of the wet clays (as discussed previously in Section 2 - Clay Liner Construction) was apparent particularly along the haul routes. Sections of clay were able to be peeled back to reveal slickensided shear faces which provide high permeability fault lines through the clay liner. As a result affected areas were reworked with the RS500 mixing machine and haul routes were built up above the height of the liner to span the clay and prevent further damage to the liner.

The author noticed that the bearing strength of the reconditioned clay appeared to increase with time particularly, when left without traffic loads. Testing of the layers showed no apparent drying out of the clay. It therefore is surmised that pore pressures generated during compaction had dissipated with time resulting in higher strength. Clay layers left for several days appeared to sustain traffic for longer periods without damage in comparison with conditioned layers which were covered immediately with another layer.

During construction of the HDPE geomembrane liner ruts and wheel marks caused by construction vehicles placing HDPE panels in position were constantly occurring. Wherever possible panels were pulled out by hand or with light weight vehicles.

Gypsum crystals were found throughout the clay liner. The sharp edges of the gypsum crystals would tear the HDPE and fail the liner if left unchecked. Hence, to avoid this problem the clay, which comprised a high plasticity clay in a very dry state, was sifted to remove all large crystals and hard, dry clay lumps. The resulting non-calcareous clay 'dust' was spread over the top of the clay liner to provide a smooth surface for the geomembrane, free of protrusions and sharp or uneven grades.

Wrinkles in the geomembrane were also observed as discussed in Section 3 - Geomembrane Liner Construction. This problem was overcome by only welding panels at night in the cool temperatures so that induced stresses in the panels were avoided during welding.

Wind continued to be a problem during the course of construction so sandbags were used to hold the liner in position. The sand bags were only finally removed once filling of the lagoon with liquor had commenced.

5.2 Landfill, Eastern Victoria

A landfill constructed in a high rainfall area located in eastern Victoria required a low permeability capping layer to prevent infiltration of rainwater into the landfill and thereby minimise the generation of leachate. The landfill product consisted predominantly of wood shavings of many tens of metres depth. The wood shavings provided a very 'spongy' subgrade which was highly compressible and was also observed to rebound as loads were removed. Sections of the landfill were poorly drained resulting in 'sink holes' of saturated wood shavings with very low bearing capacity. Areas were also observed where constant trafficking was 'pumping' water up through the fill from lower perched water areas located throughout the landfill.

Initial compactive efforts failed to meet the specified density (minimum dry density ratio of 95% Standard) due to the 'spongy nature' of the waste material which was acting as the subgrade for a low permeability clay liner. A field capping trial was conducted to assess the suitability of on-site materials and to confirm that adequate compaction and permeability could be achieved.

Various different layer thicknesses, roller types, compaction methods and materials (ranging from sandy clay to clayey sand and silty clay) were trialed. No amount of compactive effort could provide a suitably solid subgrade due to the spongy nature of the wood shavings. Landfill waste was observed to have been pumped into the first layer of clay when it was over compacted.

The trial indicated that the landfill waste could not be adequately prepared as a subgrade for construction of the capping layer, so a bridging layer was required between the subgrade and the clay liner. The most effective and efficient bridging layer available on site was a clayey sand material. The clayey sand was observed to work best when placed in a 150 mm thick layer, conditioned to near the SOMC. Considerable heaving of the layer occurred when rolled, whereby the material deflected downwards under load then rebounded to above its original level before stabilising. However, it provided a more stable base than a layer of conditioned clay liner. The author believes this may be due to the increased sand content helping to bind the layer together.

The clay liner was then able to be adequately compacted on this bridging layer to achieve the required coefficient of permeability of 5 x 10^{-9} m/s in the trials. Although the density requirements were not always met the permeability requirement, which controlled the specification, was achieved allowing full scale production to begin. Isolated soft spots of saturated wood shavings needed to be partially removed and back filled to subgrade level.

5.3 Landfill, Eastern Suburbs Melbourne

A landfill, located in the eastern suburbs of Melbourne in a relatively high rainfall area, required a side liner to prevent leachate migration beyond the site boundary. A large supply of slimes consisting of silt, sand and clay deposits in a saturated condition was being used to create the low permeability side liner. The original design called for the slimes to be supported externally by the rock face of an old quarry and internally by solid inert waste bales in turn supported by continuous landfill operations.

The slimes were pumped in thin layers and allowed to consolidate and dry through evaporation to provide a low permeability layer prior to a further layer being added. The slimes wall was expected to have sufficient strength to be constructed parallel to the perimeter walls at batter angles between 60 to 80 degrees to horizontal with internal support and landfill wastes eventually being placed on top of previous slimes layers to minimise the loss of airspace in the landfill. However, due to time restrictions and inclement weather conditions, layers had inadequate time to consolidate or dry to achieve the desired bearing capacity.

The solution to this construction problem was achieved by introducing solid inert rubble consisting of material greater than cobble size particles which contained no voids or sections capable of creating air voids in the liner. The rubble was immersed in the saturated slimes wall creating a slimes / rock matrix. Filling continued until the rock was just below the surface of the slimes liner. Piezometers were installed throughout the trial area to monitor the performance of the slimes by performing falling head tests to estimate the permeability of the slimes wall. A constant head of slimes was maintained above the layer of rubble to ensure that any consolidation and loss of water from the slimes / rock matrix was continuously replaced to minimise the risk of air voids forming. The rock / slimes matrix was then capable of achieving the required bearing strength. Ongoing monitoring of the slimes wall is continuing.

6. CONCLUSION

During the construction phase of low permeability liners including clay, geomembrane and slimes liners a variety of problems have been observed by the author. Climatic conditions and site specific conditions are often encountered.

Clay liners are particularly sensitive to moisture variation, material properties, subgrade strength and composition, rutting and shear failure of wet clay due to construction traffic. HDPE geomembrane liners are susceptible to the weather conditions and the strength and finish of the subgrade. Slimes liners can be disrupted by inclement weather conditions and material properties.

Practical solutions vary from site to site but can generally be associated with preventative measures which minimise expenses and avoid time delays caused by disruption to the construction process.

7. REFERENCES

1. Australian Standard AS1289, Methods of testing soils for engineering purposes.