The use of geosynthetics in the installation of ballast layers

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ABSTRACT

The ballast layer is an essential element of any landfill barrier design. Typically formed of soil, its function is to protect the vulnerable geomembrane below and in certain facilities, serve as a drainage layer. The ballast layer also ensures intimate contact between the geomembrane below and the underlying clay layer.

However, placing the ballast layer without damaging the geomembrane is very difficult as it requires the transport and spreading of soil material, in a relatively thin layer, onto the geomembrane using various sized plant. It has been stated in the literature that a large percentage of post construction leakage can be attributed to the construction of the ballast layer.

Geosynthetics is a new field of construction material science, ever adapting to the needs of the civil engineering industry. Possibly, the ballast layer is an application whereby the conventional method of placing a sand ballast layer is replaced by using a geosynthetic layer and in doing so, reduce the risk to the geomembrane during construction. The cost of using a geosynthetic ballast layer (GBL) alternative is also a component of the consideration.

The focus of this paper is to review the geosynthetic alternatives that can be used as a substitute for the placement of a conventional soil ballast layer. This will be achieved by reviewing available geosynthetics and assessing the results of the construction of a trial geosynthetic ballast layer in a case study.

Recommendations on the use of geosynthetics in a ballast layer will be provided.

1. INTRODUCTION

Since the promulgation of the National Norms and Standards for disposal of waste to landfill in August 2013, only waste facilities storing inert waste (Type 4) have been exempt from including a composite liner system which is formed by the combination of an HDPE geomembrane and underlying clay layers.

The thickness of the HDPE geomembrane ranges from 1.5 to 2.0mm thick, depending on the classification of the waste. The thin layer is prone to mechanical damage which leads to leakage through the liner. In order to restrain the leakage locally around the damaged geomembrane, intimate contact between the underlying clay layers and geomembrane is required. Intimate contact is achieved by applying a confining stress to the composite lining system.

Also, awareness of UV degradation of exposed HDPE has recently been investigated in South African conditions. Msiza and Shamrock (2014) considered four case studies of facilities where geomembrane that had been exposed for several years could be compared to unexposed geomembrane, say from an anchor trench. They found that in each case there was degradation occurring. In one of the case studies, the degradation was used as motivation to include a ballast layer above the primary geomembrane in the next phase of the facility.

Thermal expansion of HDPE leads to the formation of waves or wrinkles which prevent intimate contact and leads to high stresses in the geomembrane. The ballast layer both insulates the geomembrane preventing these folds from forming and restrains the geomembrane from expanding. However, folds that are entombed in the ballast layer remain entombed as found by Soong and Koerner (1998) and do not flatten out as may be expected. Rather the crest of the fold sharpens causing increased tensile stress in the crest.

Typically a ballast layer is included to prevent both mechanical damage and UV degradation while applying a confining stress to ensure intimate contact. The ballast layer may form a protective layer but it may also serve as a drainage layer in facilities that generate leachate.

2. TYPES OF BALLAST LAYER

The following types of ballast layer have been used in waste facilities:

Rock: Rock is typically used in landfill facilities in combination with a sand protection layer or protection geotextile. The rock acts as a drainage layer, allowing leachate to gravity drain to the low points of the basin, ensuring that hydrostatic pressure does not build up within the ballast layer which would be a driving force for leakage through any damaged areas.

Sand: Where circumstances allow it, sand may be used instead of rock. It does not require a protection geotextile if the particles are below a specific size (say 3.0mm). Sand may also be available on site leading to a savings for the project.

Cement stabilised sand: In facilities that will be storing liquid, the drainage function of the ballast layer is not required. Stabilising the sand that forms the ballast layer with cement provides a strong surface that prevents damage during periods where the facility is dry or being maintained.

Precast concrete blocks: Precast blocks, in combination with a protection geotextile, provide a solid protection layer for desilting of dams. The blocks can also be placed manually, reducing traffic driving on the ballast layer during installation. However, this is a costly solution and the size of the facility dictates its feasibility.

The thickness of the ballast layer is typically 300mm as stated in *Designing with Geosynthetics* [Koerner, 6th Edition]. Specifically when using compaction equipment on a cement stabilised ballast layer, a thickness of 300mm allows larger machinery to be used in the installation.

The examples above include the use of aggregate (sand, stone, cement, concrete) in order to create the physical boundary between the geomembrane and the elements that may cause damage. However, the most risk to the geomembrane is during the ballast installation - this negative aspect of the ballast layer will be discussed in a further section.

The use of a Geosynthetic Ballast Layer (GBL), although still requiring a filling, has less risk during installation due to no machinery being used above the ballast layer.

The following GBL alternatives are available:

Protection geotextile: A non-woven geotextile with a mass of 1000g/m^2 would be able to provide protection to the geomembrane. However, if used in isolation, the geotextile would be significantly degraded by UV in a short period of time and therefore is not a permanent solution. Its confining stress would also be insufficient to insure intimate contact.

Concrete filled geocells: Concrete placed in geocells provides high compressive strength ensuring protection of the geomembrane. However this is also costly and difficult to construct.

Fibre reinforced concrete: This product is formed by a thin layer of concrete, approximately 5 - 13mm thick, reinforced by fibres. It is supplied in a roll, 1.0m wide, and can be installed without the excessive use of machinery. It would serve as a good ballast layer offering good compressive strength. It’s mass, at 7.5kg per m^2, would be sufficient to ensure intimate contact. However, the convenience comes at a cost and the size of the application is directly linked to its feasibility.

Double polypropylene tubes (local): This product has been used in combination with concrete in small applications quite effectively. The product is formed by two woven polypropylene geotextiles that are sewn together with a polypropylene thread. Being a locally manufactured product, the cost of supply and transport is relatively low.

Double woven tubes (international): This product is formed by two woven polypropylene geotextiles seamed together by weaving the woven threads together. In order to combat the threat of UV degradation, a third non-woven geotextile layer is sewn on the double woven. Being internationally manufactured, the cost of supply and transport is high and dependent on the exchange rate.

A case study of using the international double woven tubes filled with tailings is presented in the following section.

3. THE SITE TRIAL

A hazardous waste facility is currently being constructed in KwaZulu-Natal. The Client, who has constructed waste facilities before, requested that the ballast layer should not be constructed using large plant driving on the ballast layer if an alternative was available. This lead to the research and development of a site specific GBL that will be filled with the same tailings that the facility is being constructed to store.

As the design of the facility was completed and approved by the authorities without the inclusion of the GBL, it was decided that a full scale site trial should be conducted to ensure that the GBL would be compatible with the tailings while serving all the functions of a ballast layer.

Four 15m long by 4.8m wide samples were delivered from the manufacturer in Germany to carry out the trial. Each sample was formed of five 93cm tubes with 8cm weaves between. It was decided to do two trials on the side slopes and two on a horizontal surface to imitate the ballast layer on the basin. See Figure 1 and 2.

The first trial was carried out on the side slope of an existing facility. The gradient of the slope was 1:2 and the supporting layer was a smooth HDPE geomembrane. The GBL was anchored at the crest using duck-billed anchors as there was insufficient space to excavate an additional anchor trench.

After the GBL was anchored at the crest, it was rolled down the side slope and pumping points were inserted at the crest. The solids stored within the facility were at a sufficient height that the GBL was horizontally supported for approximately 2.5m at the toe. The GBL was then filled with a slurry coming from the plant that contained approximately 15% solids by volume. The bags immediately filled with liquid. The solids, however, slowly started to build up in the GBL at the toe of the slope.

After various stages of filling, the bags were effectively filled with solid tailings. The consolidation of the solids within the bag after 24 hours, allowed pedestrian traffic on the bag, indicating a bearing pressure of at least 15 KPa without noticeable deformation. Therefore the GBL was considered technically viable on the side slope.

The width of the bags experienced shrinkage during the filling process. As the bags filled and increased in height, the sides of the bags were forced inwards. The bags filled to a height of approximately 450mm. Over the 4.8m width, a reduction of 26% was experienced. This information is required in the estimation of quantities for the full facility.

The next trial took place on the horizontal level of an earlier waste facility. The bag was rolled out and pumping points were installed in one end. The GBL was then filled with slurry and again the bags immediately filled with liquid.

However it was comparatively difficult to fill the horizontal bags with solids than the bags that were placed on the side slope. It was found that after a certain duration, the solids that were being pumped into the bag were equal to the solids being forced out of the side seams due to the pressure at which the bags were being filled.

At the end of the first horizontal trial, the solids did not completely fill the bags and there was approximately a length of 1m from the pumping point that did not have solids within.

Figure 1: Installation of the trial bag on the side slope – before and after filling

Figure 2: Installation of the trial on the horizontal surface – before and after filling.

During the second horizontal trial, different pressures were used as well as different locations of the pumping points (moved from centre to side of bag). The GBL was effectively filled with solid tailings indicating technical feasibility for the basin. It was decided that a pressure regulator would be required to control the pressure during the installation.

In terms of shrinkage, both horizontal bags experienced a 5% reduction in width. The bags did not fill to the same height as the bags on the side slope but filled to a height of approximately 200mm.

The second trial on the side slopes is planned to take place in late September after the plant experienced a three week scheduled shutdown in August.

4. INSTALLATION OF THE BALLAST LAYER

The typical sand ballast layer is installed using the following process:

The liner is rolled out on the prepared clay layers during the cool hours of the day.

While the geomembrane is still flat, the ballast sand is carefully placed on the geomembrane, on the same day using a small wheel mounted loader.

The sand or cement stabilised mixture is spread above the geomembrane using a small track mounted dozer – no turning of the dozer is permitted.

Compaction equipment is used if the sand is cement stabilised to ensure a sufficient strength is obtained.

Folds may be generated due to the “pushing” nature of the spreading process. As the sheet is not yet welded, the aim is to push the fold outwards towards the sides of the sheets being installed.

No folds should be entombed during the cover the process.

Once a sufficient area is covered, the ballast for the following geomembrane panel is heaped on constructed ballast in preparation for moving it onto the next sheet after it has been welded to the previous sheet. This implies that the trucks carrying in the ballast material will be driving on ballast on installed geomembrane.

Sheets are only welded together when they have reached the same temperature.

The process of installing a GBL (double woven tube alternative) is as follows:

The liner is rolled out on the prepared clay layers during the cool hours of the day;

The GBL is laid out above the geomembrane and is secured with UV stabilised sand bags and rope;

The GBL will prevent UV degradation of the geomembrane as well as mitigate its thermal expansion causing fewer and smaller waves to occur.

If the GBL is going to be filled with tailings, the filling process cannot commence until the entire geomembrane installation is completed. If it is going to be installed with sand slurry then filling could proceed immediately. Either process will require the ability to pump the filling into the bag.

If the GBL is going to be installed with slurry, there will be liquid generated at the low points of the facility which will need to be continuously pumped away. If the slurry is tailings, the liquid will be contaminated and will need to be pumped to another facility. Either way, operations of filling the bag will require constant management of liquid.

5. THE POSITIVE AND NEGATIVE ASPECTS OF USING A GEOSYNTHETIC ALTERNATIVE

The main positive aspect of using a GBL alternative is keeping machinery off of the liner system.

Nosko and Touze-Foltz (2000) found that when considering the results of electrical leak detection surveys carried out over 300 sites covering a lined area of 3 250 000m^2, that 77.8 % of the damage occurred on the basin and that 15.59% of the damage was due to heavy equipment driving on the cover layer above the geomembrane. Removing this risk in the first place should lead to less damage occurring during installation.

Another main positive aspect is that the GBL can be filled with tailings which means that it is not taking up valuable airspace in the facility. This can be viewed as waste re-use and is aligned with Goal 1 of the National Waste Management Strategy of 2012.

The negative aspects of using a GBL are the following:

UV degradation: This is more of a concern on the side slopes than on the basin which is usually covered shortly after commissioning. The UV exposure consumes the antioxidants within the geosynthetic which leads to the engineering properties of the GBL breaking down.

Veneer stability: Textured geomembranes have increasingly assisted in ensuring that liner systems are stable on the side slope. However, introducing a geosynthetic interface where there used to be a sand interface leads to less friction being transferred specifically if the GBL is going to be filled with slurry. Koerner and Narejo (2005) report that the typical interface residual friction angle between a textured geomembrane and a woven geotextile is 18° which is slightly lower than the angle of a 1:3 slope (18.4°) typically used in waste facilities, suggesting instability. The typical interface residual friction angle of a textured geomembrane and a gravel material, reported in the same document, is 31°, which would have a high factor of safety against instability. Ideally site specific shear interface testing or full scale tests should be carried out.

Anchorage: The reduced veneer stability is less of a concern if the GBL is suitably anchored at the crest. As it will be installed at the same time as the primary geomembrane, it may share the same anchor trench.

Time to fill bags: Filling the bags may be a longer process than constructing a conventional ballast layer. Instead of placing and spreading the ballast layer with large machines, the GBL is manually unrolled and then each bag is individually filled. This will require on-going and dedicated operations.

Cost: The cost of the GBL can vary significantly depending on where it is manufactured and what filling material is used. The thickness of the ballast layer also has an effect on cost as it is consuming valuable airspace. A cost comparison of options from the case study is presented in the following section.

6. THE COST COMPARISON

Table 1 shows the construction cost comparison of four different ballast layer options that was carried out for the case study facility:

Table 1: Comparative costs of different ballast layers

No.	Alternative description:	Cost per m^3 of waste stored	% more than lowest	Cost per m^2 of liner footprint	% more than lowest
1	300mm cement stabilised sand ballast layer (site sand used), protection geotextile of 1000g/m^2 included	R 129	8.4%	R 885.11	4.4%
2	Fibre Reinforced Concrete Ballast Layer (thickness negligible)	R 189	59%	R 1347.99	59%
3	Double polypropylene tubes (local), filled with cement stabilised material, 100mm thick.	R 124	4.2%	R 872.57	3.0%
4	Double woven tubes (international), filled with tailings – based on exchange €1 = R 14.35 (thickness negligible)	R 119	-	R 847.44	-

The GBL in Option 4 is the least expensive option as it is filled with tailings and therefore does not have a filling material cost attached. The operation of filling the bag is not considered under construction costs but under operations.

Option 2 is excessively more expensive and relates to the size of the facility in the case study.

Option 3 may have been less expensive if filled with tailings. However, the method used for joining the two woven geotextiles raised a concern that the GBL may not have sufficient strength for the pressure generated by the tailings on the sideslope.

The UV resistance of Option 3's GBL was also unknown. However, the degradation was less of a concern if cement stabilised material was used as it would maintain its own shape after being cast, so the GBL would only be temporarily required to give the ballast layer shaping while it set.

Option 1 is the conventional cement stabilised ballast layer used in the original design before consideration of a geosynthetic alternative commenced.

When comparing the costs of per m^3 vs. per m^2 the benefit of storage savings (i.e. thinner ballast layer) becomes apparent as the m^2 cost estimate would not take account for this. However, the cost difference increases significantly for Option 1 when the cost per m^3 is calculated as this is the thickest ballast layer and therefore the most volume is lost.

7. CONCLUSIONS

The trials of the GBL have indicated that it is technically possible to install a ballast layer without the use of machinery which shall significantly decrease the risk of damaging the liner while installing the ballast layer.

One of the major unknowns is how long it will take to fill the GBL with tailings and the intensity of care required during the filling operation. This question may soon be answered as the GBL being developed for the case study continues to show merit.

Early indications are that it is a new application of geosynthetics.

8. RECOMMENDATIONS

If there is interest in using a GBL in a future project, the following recommendations are made from the experience gained to date:

Approach a geosynthetic manufacturer that is keen to do research and development and can provide technical assistance. The supplier will assist with the development of the GBL while the Engineer can focus on the site requirements. Carrying out a trial will be mutually beneficial to the supplier and the client and therefore required resources are shared.

Engage with the design approval authorities as soon as your decision to use an alternative is made. Their input, in the form of concerns raised, allows for an external assessment of using the alternative and may highlight aspects that require further consideration.

Carry out a full scale site trial as soon possible. A successful trial assists with addressing concerns that are raised from the theoretical consideration of using a GBL – the case study trial assisted with addressing the following questions:

- Will the GBL fill with solids?
- Will the GBL perform all the functions of the ballast layer?
- Are the filling operations feasible?

The site trial also gives the manufacturer a chance to become familiar with the site conditions which can help with further optimisation of the GBL, while allowing the Engineer to gain experience of the GBL, allowing optimisation of the site conditions.

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