A new safe and sustainable approach for constructing ballast layers for waste containment facility liner systems

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ABSTRACT: Ballast layers are used to protect a containment facilities primary liner against U.V. radiation and thermal expansion whilst also ensuring intimate contact between the liner and underlying layers. Traditional ballast solutions comprise soil layers (typically enhanced with additives such as cement or bentonite) or concrete. The existing solutions require mechanical plant to drive above the primary liner during installation and research has shown that such operations significantly increase the risk of damage (leakage) to the lining system. A flexible geosynthetic mattress ballast (GBL) layer has been developed to provide the required performance characteristics of the ballast layer, whilst mitigating damage during installation above the primary liner. Further advantages of the GBL include potential re-use of waste, which has large environmental advantages, including lower carbon footprints and zero reduction in the available storage space of the facility. Practical aspects from a case history will also be presented.

1 INTRODUCTION

The development of geosynthetics continues to grow each day. New applications of geosynthetics are being found that form from overlaps of existing functions such as protection, separation, filtration and drainage. One such new application was developed and continues to show promise after it was implemented in a tailings storage facility back in 2015. This is the application of the Geosynthetic Ballast Layer (GBL): A new product that was developed to reduce the damage caused during conventional ballast installation processes.

The GBL is an “innovative geotextile containment system utilizing state-of-the-art weaving technology, which provides a tubular system interconnected into a singular geosynthetic mattress configuration which is filled with waste product (Huesker, 2016, p. 19)” and becomes the main ballasting medium. For the case study discussed, this material is industrial mineral waste which is pumped to the facility in the form of slurry. However, in other applications the filling material could range from sand to concrete.

A further optimization is the addition of a non-woven geotextile stitched to the exposed side slope layers to counter UV degradation of the underlying woven geotextile. This optimization was included as part of the case study project as the ballast layers on the side slope take longer to be covered by the waste body due to the filling process.

A further potential advantage of the GBL relates to sustainability and this topic is introduced and discussed in more detail within this paper. The main advantage is that the site waste product for which the waste containment facility is being constructed is also used to create the ballast layer itself (as part of a geosynthetic/waste composite structure), which has large advantages in terms of sustainability for site operations. It is also worth highlighting that site owners can consider carbon off-setting as part of their operations (this subject is not dealt with further in this paper).

2 PREVIOUS RESEARCH

At Landfill 2015, the GBL was first introduced (Cilliers, 2015). The idea behind the ballast layer was to create a protecting layer above the primary geomembrane of a waste facility without using conventional methods of placing a typical ballast layer with large construction plant. Nosko and Touze-Foltz (2000) found that placing the ballast layer in this way was the largest contributing factor to leakage due to damage of the primary liner.

The GBL would need to fulfil all the features of the conventional ballast layer mainly: protecting the primary geomembrane from mechanical and UV damage, applying a confining stress to ensure intimate contact between the primary geomembrane and the underlying clay layers and ensure that no folds, due to thermal expansion, are entombed in the primary liner during installation.

Huesker have a long history of manufacturing Soiltain dewatering tubes made from woven geotextiles. Huesker also have a product range named Incomat, which effectively is a geotextile formwork that acts as a surface sealing system while protecting against erosion, mechanical damage and buoyancy, forces being traditionally filled with concrete (Huesker, 2016). Huesker and Jones & Wagener worked together to create a GBL prototype based on the concepts of the Soiltain dewatering tubes and Incomat products. The GBL concept was then discussed and offered as an alternative to a Client who was in the early stages of constructing an industrial waste facility. The facility was planned to have a Class-A liner system (South African Norms and Standards, 2013) with a conventional cement stabilized sand ballast layer. The Client agreed to start with site based trials to see if the GBL would be able to perform the required functions of the conventional ballast layer (CBL).

The trials were carried out both on the side slope of an earlier phase of the waste facility and on the horizontal surface of a filled waste facility to mimic the basin of the new facility.

The results were sufficiently successful to adapt the design to use the GBL as the entire ballast layer in the new facility. The trials also resulted in essential information such as expected shrinkage during filling which is later used to size the overlaps on the ballast layer panel layout. The trial also provided an indication of the difficulty of operations involved to fill the bags. The results of the trial were presented at the Landfill 2015 conference.

This paper continues to present information of the practical elements experienced from the end of the trial stage, throughout the manufacturing process, to the commencement of installation at site and also introduces a comparison between the GBL and CBL in relation to sustainability.

3 SUSTAINABILITY

The term sustainability can be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). One of the main indicators of sustainability is CO2 emissions.

Sustainable low carbon construction targets are being set by several countries, through governments and/or funding bodies (e.g. Asian Development Bank). The construction industry’s drive for sustainable practices are focused on reducing CO2, because CO2 reduction contributes to national targets for reducing overall greenhouse gas emissions (Koerner, 2016). Carbon foot printing techniques are used to establish the embodied carbon for a solution over set life cycle boundaries. A key component of any such assessment is the embodied carbon of the materials used within the construction solution.

Appropriate geosynthetic solutions can improve the sustainability credentials of a construction project (WRAP) compared to more traditional construction solutions. Following recent research in Europe (Raja et al, 2015), the accuracy and repeatability of assessing the embodied carbon of geosynthetics is improving.

The relevant European Union harmonized conditions (EU No 305/2011, 2011) relate to the Construction Products Regulation (CPR) and provide a common technical language to assess the performance of construction products and ensures that reliable information is available to professionals, public authorities, and consumers, so they can compare the performance of products from different manufacturers in different countries trading within the European Union. Clause 55 of the CPR states: "The basic requirement for construction works on sustainable use of natural resources should notably take into account the recyclability of construction works, their materials and parts after demolition, the durability of construction works and the use of environmentally compatible raw and secondary materials in construction works".

Clause 56 of the CPR states 'For the assessment of the sustainable use of resources and of the impact of construction works on the environment, Environmental Product Declarations (EPD) should be used when available'.

HUESKER has undertaken detailed analysis of its CO2 emissions through its EPD certificates (EPDs, 2014 & 2016), which provide a full life cycle analysis (LCA), including carbon usage, assuming a cradle-to-gate model. The embodied carbon can now be accurately calculated for certain geosynthetic products and solutions.

The GBL solution was compared against the CBL. The CBL considered comprised a 300mm thick (compacted thickness) cement stabilized sand layer. The sand is sourced and screened on-site to reach a uniform grading size. The purpose of this example is to carry out an Embodied Carbon comparison of the two solutions and is based on an example calculation carried out for a site in South Africa assuming a 1ha area of site and is based on a cradle-to-end of construction comparison (EC values for production, transport to site and construction). Common activities for both the geosynthetic and traditional ballast solutions can be omitted, as they cancel each other out with respect to comparison and this helps simplify the analysis. It is highlighted that the activities accounted for in this case study are by no means exhaustive, and a more rigorous study may include country specific values for South Africa and a more detailed breakdown of construction activities on site. Nevertheless, the exercise remains valid and provides a clear overview and comparison of the two construction techniques in terms of carbon emissions.

Table 1 provides a summary of the input parameters to allow comparison of the two ballast solutions (i.e. CBL and GBL) in terms of EC. The value chosen for the geosynthetic EC value was 3.0 kgCO2e/kg (Table 2), which is based on an averaged value from the combined EPD certificates of HUESKER, taking into consideration the amount of raw material used in the GBL (i.e. ~650 g/m2 for the 3-layer material). This approach is conservative because the majority of the GBL used is a lighter weight two-layer material, which does not include the sacrificial nonwoven upper geotextile layer. Therefore, the overall EC value of the GBL is likely to be lower for many of the future projects. It is worth highlighting that the study by Raja et al (2015) highlights the significance of geosynthetic weight in terms of sustainability as the embodied carbon of the raw polymer accounts for approximately 80% of the final EC for a geosynthetic product at the gate (i.e. cradle-to-gate). Therefore, in order to achieve the optimum sustainability from a geosynthetic based construction solution, the geosynthetics must be used appropriately in design and also the polymer used efficiently in producing a material that can achieve the design criteria (Koerner, 2016).

The EC values for the cement stabilized sand to form the CBL are taken from published literature (Hammond et al, 2011) and then multiplied by the amount of material required to form the CBL (Table 2).

As the EC values for the GBL are cradle-to-gate (i.e. to the point of manufacture and ready for delivery from production plant) additional values for transport to site are required (Table 3). The calculation of the EC for transport (Equation 1) considers the distance travelled and the emissions of the transport mode. For this comparison it has been assumed that the cement was sourced locally within South Africa and the site is 300km from the cement production factory. For the road transport (both within Europe, where applicable, and South Africa), a 20t rigid Heavy Goods Vehicle was assumed with a fuel consumption of 3.33km/liter (U.K. Department for Transport, 2012) and CO2 emissions for diesel of 2.60 kgCO2 per liter of fuel (Defra, 2013). Values may differ for other Countries and reference made to the local guidelines/publications, if available.

$$C = (\beta\,(2D/\alpha))/1000Q \qquad [1]$$

C= Total CO2 emissions per ton (tCO2/t),
D= distance of transportation (km)
α= Fuel consumption of rigid HGV
Q= Quantity of material (tons)
β = CO2 emissions per liter of fuel.

Table 1 – Input values for EC calculation

Property	Value	Units
Input data for Cradle to Gate		
Area	10,000	m^2
GBL mass per unit area (unfilled)	0.65	kg/m^2
GBL cradle to gate EC value (Raja et al 2015)	3.00	$kgCO_2e/kg$
CBL mass per unit area	2000	kg/m^3
Cement stabilized soil (8% cement) cradle to gate EC value (based on Hammond and Jones, 2011)	0.084	$kgCO_2e/kg$
Additional Data for cradle-site		
GBL Transport Distance (road)	675	km
GBL Transport Distance (sea)	16,000	km
Sand Transport Distance (on site)	0	km
Cement Transport Distance	300	km
α= Fuel consumption of rigid HGV	3.33	km/l
β = CO_2 emissions per litre of fuel HGV	2.60	$kgCO_2$ /litre
α_s= Fuel consumption of ship*	45	Km/l (per container)
β_s = CO_2 emissions per ton-km – Ship**	0.01	$kgCO_2$/ton-km
Additional Data for cradle-end-of-construction		
Sand Layer thickness	300	mm
Compaction effort	1000	m^2/hour
Compaction Plant Fuel Usage	16.0	litres /hour
β = CO_2 emissions per litre of fuel	2.60	$kgCO_2$ /litre

* https://en.wikipedia.org/wiki/Energy_efficiency_in_transportation
** http://people.exeter.ac.uk/TWDavies/energy_conversion/Calculaion%20of%20CO2%20emissions%20from%20fuels.htm

Table 2 - Calculated EC values

GBL mass	6.5	t	CBL mass	6000	t
			Cement mass (based on 8% cement ratio)	520	t
Geosynthetics Total Embodied Carbon	19.5	tCO_2e	CBL Total Embodied Carbon	504	tCO_2e

Table 3 - Calculated transport emissions

Distance	675	km	Distance (for cement)	300	km
Truckloads road	1		Truckloads	1	
Distance sea	16000	Km			
Container sea	1				
GBL transport emissions	1.162	tCO_2e	CBL transport emissions	0.468	tCO_2e

The construction plant emissions in this case account for the main carbon producing aspects of the construction. For the GBL the construction emissions are considered to be zero because any emissions produced due to the movement and positioning of the rolls of GBL with construction plant are vastly offset by the direct pumping of waste from the processing plant into the geosynthetic material to form the GBL. For the CBL, the construction emissions to spread and compact the CBL are calculated (Table 4).

Table 4 - Construction emissions

CBL Number of layers	1		GBL Number of layers	1	
Time for 1 compaction pass (full area)	10.00	hrs			
Number of passes / layer	4				
compaction time	40	hrs			
Fuel consumed	640	l			
CBL compaction emissions	1.66	tCO_2e	Total for geosynthetic construction	0	tCO_2e

Table 5 provides a summary of the total Embodied Carbon emissions including the material, transport and construction totals. It is clear that the majority of the EC emissions are produced during the production of the material used to form the ballast layer. For the CBL, if the sand had been sourced off-site the EC emissions for transport could also have been high, due to the bulk volume of the sand. The use of the waste product to fill the geosynthetic for this case study has a huge advantage from a sustainability point of view. Although not discussed as part of this paper, further research on the advantages of carbon off-setting, related to the use of waste to form the ballast layer would also be highly interesting.

Table 5 – Total calculated Embodied Carbon emissions

	Embodied Carbon emissions (tCO_2e)			
Solution	Embodied	Transport	Construction	Total
CBL	504	0.468	1.66	506.3
GBL	19.5	1.162	0	20.7

4 PRACTICAL ASPECTS

Due to the nature of the GBL, in its current form, it needs to be manufactured to size. Therefore a panel layout needs to be agreed upon between all parties. This panel layout becomes the official plan from which the material list is generated. The material list is formed from two sections: basin and side slope. Each panel has a corresponding number and length. The panels are also placed in a specific sequence such that the delivery schedule of the panels can be matched to the construction schedule if required. It is also important to note for side slope panels that additional length was added before and after the required length of side slope to cater for anchorage and toe support.

Knowing the method of installation before manufacturing also assists in packaging the bags such that deployment is carried out efficiently and correctly on site, this is assisted by printing suitable labels on the GBL panels. This helps specifically for the side slopes where the non-woven geotextile needs to face upwards as well as a certain length be placed at the top of the crest for anchorage.

Strict adherence to the setting out of the facility during the earthworks stage is required to ensure that deviations between panels manufactured to size and the as-built dimensions of the facility are compatible. The consequence of incompatibility is that the panels will not cover the full footprint of the liner at installation stage and additional panels will need to be supplied leaving some primary geomembrane exposed unless a temporary sacrificial cover layer is used.

Filling of the GBL with mineral waste slurry has commenced now that the installation is complete. It was estimated that it would take up to 5 months from when the first ballast layer is installed to when the first ballast layer is filled with slurry (the actual period turned out to be 24 months). Therefore the ballast bags needed to be suitably held down against wind uplift during this period.

Giroud, Pelte and Bathurst (1995) published equations to calculate the size and spacing of sand bags to suitably restrain geomembranes against wind uplift. The equations consider wind speed, altitude and suction factors that differ for the location of the geosynthetic whether it be placed on the basin, side slope or crest. These equations have been used to size the spacing for the ballast layer and are considered conservative as the ballast layer is more permeable than geomembrane and shouldn't experience as much suction from the wind.

The results of the equations indicate that the following spacing is required for temporary ballasting with sand bags:

- 1.25m spacing on the side slopes
- 1.80m spacing on the basin

While this spacing may seem conservative, the wind speeds in the location of the site during the autumn season are very high and previous facilities constructed during this time have had significant blow-outs of geomembrane which need to be replaced. The spacing is only used as a guideline; the spacing of the bags also need to consider the overlaps and ensuring that the ends of the layers where the wind could get below the layer are suitably sealed.

It was also essential to ensure that both the rope that holds the sandbags in place and the actual bags used are manufactured from UV resistant material. The first few sheets that were installed with the above bag spacing and are illustrated in Figure 1.

With any application of geosynthetics, veneer stability should always be assessed to ensure there is little risk of slippage. In terms of this installation, the GBL is being installed on textured geomembrane. Koerner and Narejo (2005) states that the expected residual friction angle between a woven geotextile and a textured geomembrane is in the range of 18°. On a 1[v]:3[h] slope of 18.4°, some slippage would be expected if no additional anchorage takes place at the crest. However, the intention is to securely anchor the GBL at the crest as illustrated in Figure 2. The ballast layer is placed in the same anchor trench as the geomembrane which ensures no sliding on the top surface of the geomembrane. This is then followed by a cement stabilized layer that will further anchor the ballast bag to the crest while completing the final ballasting functions as the slurry within the bags will not be able to extend beyond the full service level of the facility.

Figure 1: The geosynthetic ballast layer installed on the side slope and suitably ballasted with UV resistant sand bags and rope. The GBL is white due to the exposed non-woven geotextile being stitched to the underlying black woven geotextiles.

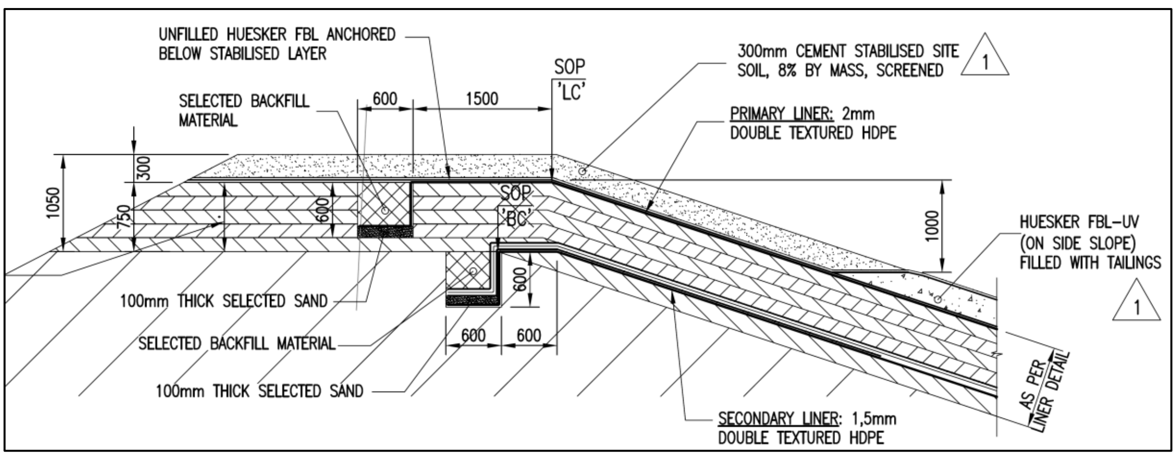

Figure 2: Anchorage detail of GBL at the crest

Figure 3: Construction of the cement stabilized soil perimeter cap. The GBL in the basin does not have a white non-woven geotextile stitched to the surface, as these will be filled first.

In order to fill the ballast bags, a pump point has been installed at the low points of the basin. During filling of the bag, there is continuous flow of liquid being generated from the dewatering process which drains to these low points. The liquid pools at the low point and will eventually need to be pumped out to another waste facility. Therefore these low points needed to be in place before the pumping of slurry into the ballast layer commenced.

Figure 4 illustrates the detail of the pumping low point. While the Concrete Canvass product may not be financially viable to use as a ballast layer over large areas, it provides convenience in the form of providing a good hardened surface for pumping activities which is easy to install and also does not pose significant threat to the primary geomembrane during installation.

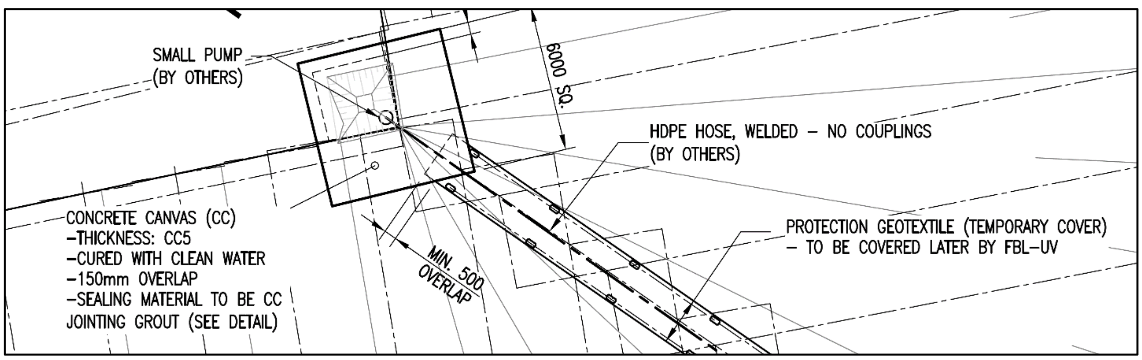

Figure 4: Pumping point detail at low spot of basin

5 OPERATIONAL ANALYSIS

The site trial of the ballast mattress took place on top of a smooth geomembrane on the side slope of an existing facility. From this trial, the estimated shrinkage of 26% was used to design the panel layout, taking into account the size of overlaps required. However, it is assumed that the shrinkage would be less on a textured geomembrane as there should be more resistance to the ballast moving on top of the geomembrane. This, however, leads to a conservative estimate of ballast material required.

During the same site trial, the ballast mattress was relatively easy to fill on the side slopes, however, the horizontal layers appeared challenging to fill completely. By making small changes to the entry position of the inlet and the pressure at which the slurry was pumped into the ballast mattress, it was effectively filled with solid tailings. Afterwards it was decided to control the pumping using a pressure regulator during installation (Cilliers, 2015).

The operations that will be required to fill all the ballast bags is expected to be a long process. There is approximately 38 000m^2 coverage of ballast layer on the side slope and similar on the basin. This results in approximately 490 ballast layer sheets that need to be filled. Assuming a production rate of one sheet a day this is approximately 22 to 24 months' worth of daily operations.

As the intention of using a GBL is to prevent damaging the primary liner, the filling operation is being carried out carefully and under supervision. While the non-woven geomembrane added for additional UV protection is considered to be sacrificial, the effect of solar radiation on the ballast bag is visually evident as shown in Figure 5, where at the time the trial ballast panel on the side slope had been in place for 12 months. Samples of this geotextile have been taken for testing and reporting on the degradation of the cover layer will be discussed in a future paper.

Figure 5: UV degradation evident on non-woven sacrificial geotextile cover on side slope ballast layers.

6 INITINAL FILLING EXPERIENCE

Filling of the first few GBLs has commenced in the basin. The Client is currently optimizing the form of manifold to use to fill the bags – see Figure 6. The manifold is formed by a perpendicular base HDPE pipe with 5 HDPE off-shoots each entering one of the tubes of the GBL. Slurry is then pumped through the manifold from the plant. The addition of a ventilation pipe at the end of the manifold has assisted in air flow during the filling process. Initially, a ball valve was added to each off-shoot pipe to control the flow. However, these were in the process of being removed as they did not serve a function during filling.

Figure 6: Optimized manifold showing ventilation pipe

One of the difficulties is ensuring that the entire bag is filled over the 50m length in the basin. During filling, the entire bag fills with liquid so it is difficult to observe where the solids are settling and whether the entire bag is full of solids. In some cases, the solids settled near the entrance by the manifold. In other cases, the solids settled near the end of the bag and in others the full bag was successfully filled as shown in Figure 7. The result is that the manifold can not be left unattended during the filling process and requires constant monitoring.

Figure 7: Successfully filled GBL on the basin

Other difficulties include removing all the sand bags as they interfere with the filling process. Any liquid above the ballast bags also interferes with the initial filling of the bag with liquid therefore it is essential to ensure that all excess liquid reports to the low point where the pump pad is located.

No GBL bags on the side slope have yet been filled, however, the lessons learnt in terms of optimizing the manifold and ensuring even filling of the bag will likely lead to an easier process – gravity filling on slopes. The sand bags were also placed on the sides of the GBL on the side slopes, therefore should be less of an interference during filling.

7 COST CONSIDERATIONS

In the Landfill paper (Cilliers, 2015), the costs of various ballast layer alternatives were presented. When comparing the costs of storage savings per m^3, the cost of the geosynthetic ballast layer did compare favorably to the alternatives. However, it must be noted that this was based on a specific exchange rate at the time *(€1 = R 14.35)*. As the GBL was the only international product in the comparison, its cost is influenced by exchange rate fluctuations. With current rates, there would be an approximate cost increase of 10% that would need to be considered when comparing to alternatives.

8 CONCLUSIONS

The GBL is an exciting new application of geosynthetics in lined facilities. It shows promise in providing all the essential services of a ballast layer while significantly decreasing the risk of damage to the entity it ultimately aims to protect, the primary geomembrane.

The filling process has commenced and some early challenges include optimizing the manifold used to fill the bags as well as ensuring an even distribution of solids over the length of the bag. These challenges are expected for an operations-intensive alternative and should not be a deterrent for future applications of the GBL.

In terms of sustainability the use of the GBL for the case study highlights a very large saving (i.e. >2300%) in Embodied Carbon emissions compared to the CBL. The main reason for this is the use of the waste product on site to form the ballast layer within the geosynthetic. Other advantages not discussed in this paper, but worth highlighting, include the saving in void space of the waste cell i.e.

the CBL would have taken up 0.3m of space which is now filled with the same waste product that will be placed in the cell when construction is complete.
For this project the total storage capacity was increased by 3% to 4% or 150,000m^3. There is also the monetary and time saving for installing the GBL compared to conventional layers. The site owner/operator can now also potentially off-set carbon and/or gain carbon credits due to re-using the waste as part of the construction. This subject requires further research into the local South African guidelines on carbon credits and off-setting to see if there would be a potential further advantage.

This paper and the case study discussed, highlights the importance of considering several factors when selecting the optimum ballast layer, including but not restricted to: project sustainability improvement, greater use of waste products, increased void space for waste depositing and overall project cost savings. The suitability of using the GBL compared to CBL should be assessed on a project-by-project basis.

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