GUIDELINES TO THE DESIGN OF A LANDFILL FACILITY

LANDFILL INTEREST GROUP: SEMINAR SESSION 2: OVERVIEW OF LANDFILL FACILITY DESIGN AND ASSOCIATED INFRASTRUCTURE

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1. INTRODUCTION

The purpose of this presentation is to touch on the aspects to consider during the design phase to establish a new landfill facility and / or to extend an existing facility. This presentation will however not cover the finer details in the design process due to time constraints.

For the purpose of this presentation it is assumed that the following has already been covered in the previous LIG Seminar Session 1:

- a waste licence has already been issued; and would have included the identification and ranking of various alternative sites (part of EIA process);
- a preliminary design would have determined waste volumes, life time, final shape and end use of the site.

2. TOPOGRAPHICAL SURVEY

Digital terrain modelling (DTM) is extensively used for the landfill design as well as the landfill development (waste body). To be able to do the DTM one requires a topographical survey from which one can generate contours which would form the bases of the design. This is done by land surveyors and is then manipulated by the design engineer to form the landfill site contours and determine cut and fill volumes. This can enable the design engineer to maximise airspace and construction material at optimal costs.

3. SITE LAYOUT AND PHASES

One of the most critical phases in the establishment of a new landfill facility would be the overall site layout. Much thought must go into the layout taking all factors into account, not only the landfill itself. The access roads, office buildings, workshop, weighbridge, storage dams (if any) etc. need to be placed in such a way that it will serve its designed purpose for the duration of the site's operating life. This would, however, have been basically covered during the license application process. In the initial phases of a new facility on a clean piece of land, this is normally not that difficult, but designing extensions to existing and established sites can become problematic often resulting in existing infrastructure having to be relocated. As a result it is very important to put much thought into the initial development plan of a new landfill facility to avoid future relocation costs for infrastructure. Practical consideration must be given to the site layout, such as to avoid contact between stormwater and contaminated run-off water, gravitational leachate collection and using your first cells for screening, etc.

Infrastructure

When designing a new waste facility it is ideal (if practical) to place all permanent infrastructure (offices, workshops, weighbridge) in the corner of the erf, as close as possible to the erf boundary closest to the incoming access road. This will optimize the property to obtain maximum airspace and to provide somewhat of a visual shield / barrier for the passing traffic. This is, however, not always practically possible and less ideal options may need to be considered.

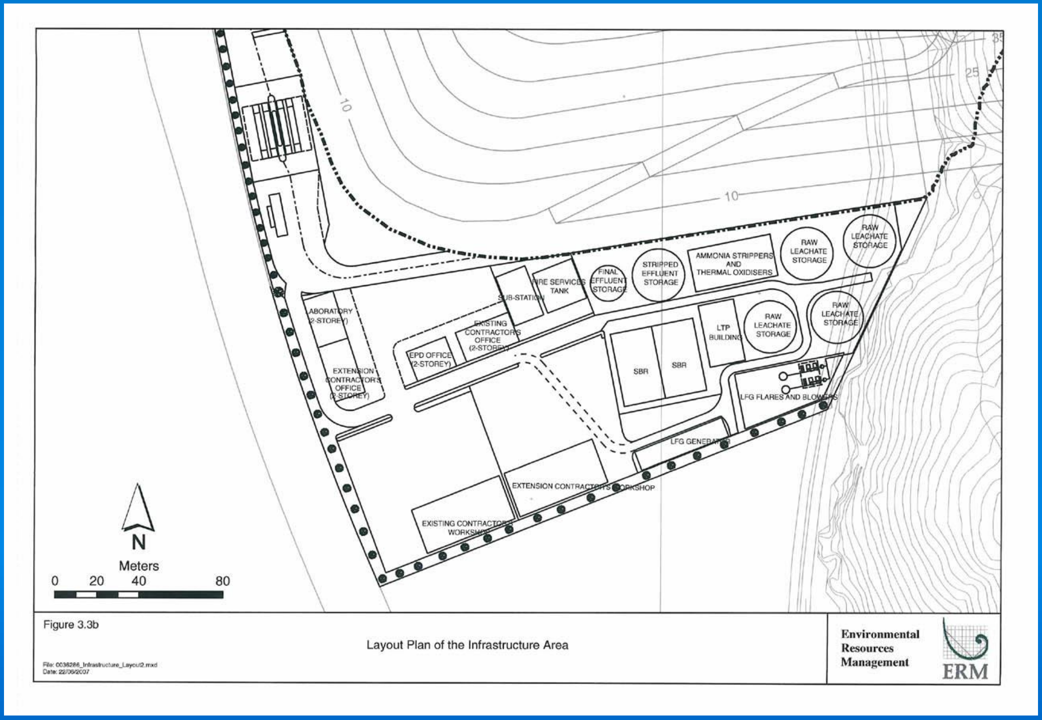


Figure 3.3b
Layout Plan of the Infrastructure Area

Permanent infrastructure like weighbridges and wheel washers (if any) should be designed and spaced to allow for quick and easy vehicle movement and to avoid queuing. It is advisable to have two weighbridges if possible, one for weighing in and a separate one for weighing out.

At smaller and less busy landfills it is possible to make use of only one weighbridge for both functions. There are various types of weighbridges but due to the amount of dust, mud etc. associated with a landfill site it is important to choose a weighbridge that can be cleaned from underneath and also have easy access to the load cells for servicing.

The weighbridge should be positioned far enough “into” the site or at least away from a busy public road as to prevent trucks waiting to be weighed in from having to queue on a public road.

The location of the workshop or vehicle camp should not hinder the flow of traffic. Due to the heavy machinery used on the landfill it is important to keep this plant away from the normal access or public roads. Special attention should be given to the proposed roads (surfacing) to be used by the operational plant, especially the landfill compactor. One would like to avoid the landfill compactor crossing any of the permanent roads due to the damage they can cause with their cleated wheels.

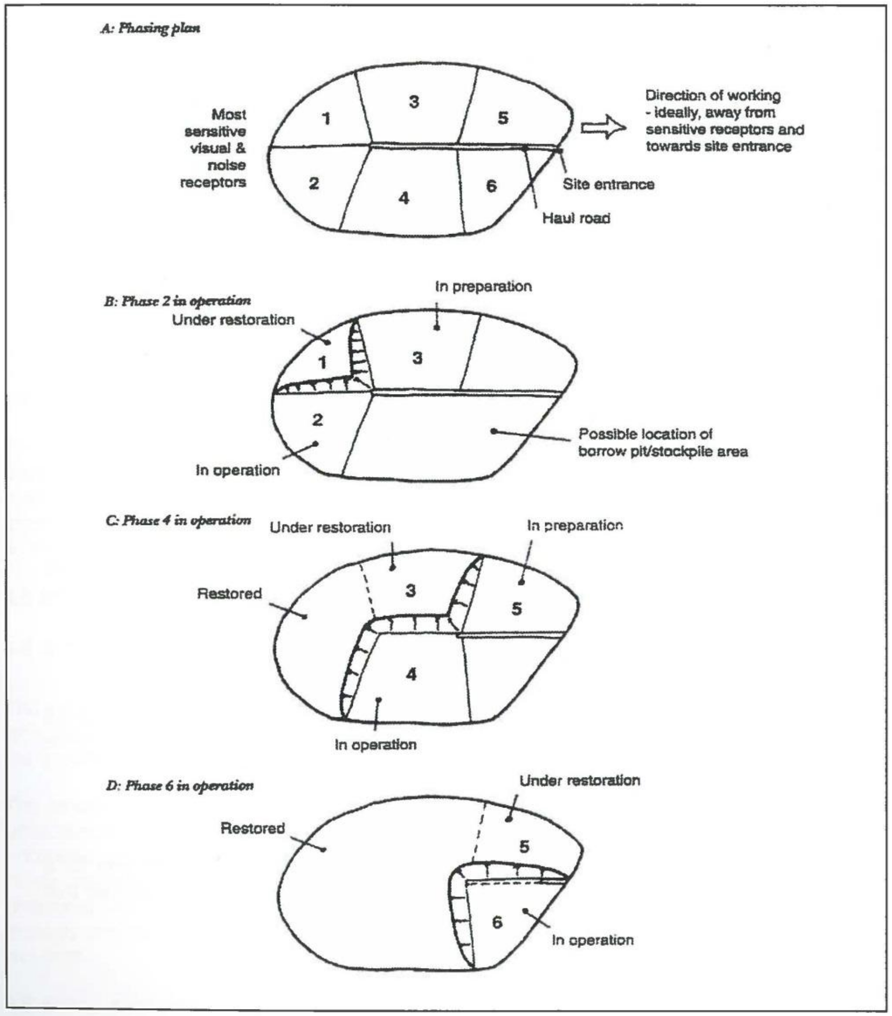
The location of perimeter security fencing should not get in the way of future infrastructure but should not be so remote as to be stolen or vandalised.

Landfill Cells / Phases

It is good practice to develop and operate a landfill in a series of phases or cells (subdivisions of a landfill) of optimal size. A balance must be found to minimise impact areas such as working surfaces, contaminated stormwater catchment area, and leachate generation, while optimising the construction costs and providing enough airspace. Typically, a cell should be designed to last for approximately five years. A five year period provides enough time for the design, construction and placing of the pioneering layer in the following cell. Depending on climatic conditions and the amount of bulk earthworks required for the establishment of a new cell it takes typically 18 – 24 months to complete, pioneering layer included. The location and order of development of these phases should be carefully planned in advance and be adhered to, to avoid future complications.

It is preferable to work from the lowest point of the landfill towards the higher areas in order to accommodate leachate drainage and prevent possible overflow of leachate onto unlined / undeveloped lower areas (should higher areas be developed first).

Figure 20: Phasing: Site Division into Cells and Sections[66]



It is also preferable (if possible) to develop the cells from the most sensitive visual & noise receptors and work away from them and towards the landfill entrance. The design engineer must aim to fill each cell to final level, especially the final outer slopes. This will then make it possible to remediate or at least temporarily cap the outer slopes to reduce leachate generation, divert clean run-off from the side slopes away from the landfill and enable the vegetation or stabilisation of that slope for a more aesthetical appearance and slope stabilisation to screen the active cells. Steeper slopes than a 1:3 gradient will make the remediation process difficult and could cause stability issues; especially if there are geosynthetics in the capping layers. It is also problematic to place and compact clay layers on slopes steeper than a 1:3 gradient.

Care should be taken to place stockpiles of excavated material to be used in future cell layerworks, so as to prevent double handling. If possible this material should be placed outside the footprint of future cells, or if not possible, at least in an area where the material would be used before the development of the area on which the stockpile is located.

On-site access roads should be kept in a neat condition and should be graded that all plant / trucks will be able to use them in all weather conditions. The roads must also be structurally designed to last for their operating lifespan. On-site roads must be geometrically designed and aligned to be able to accommodate heavy vehicles with large turning circles and the trucks must be able to use the on-site roads during all weather conditions. A longitudinal slope of 1:10 is regarded as an acceptable slope for most vehicles. Too steep slopes could cause inaccessibility to certain areas, especially if the trucks are still full of waste and could delay turn-around time, could cause mechanical damage to the vehicles and lead to the dumping of waste on unwanted areas.

Proper initial stormwater management planning is crucial during the site layout to ensure proper drainage of contaminated as well as clean run-off from current and future cells with minimal alterations to the existing infrastructure throughout the development of the landfill site. As the treatment of contaminated water or leachate is usualy expensive, volumes of water requiring treatment must be minimised as far as practically possible. This would require that external or uncontaminated stormwater must always be diverted around waste bodies or contaminated water to prevent contact and contamination. The design aspects of the stormwater management system will be discussed later.

4. GEOTECHNICAL AND GEO-HYDROLOGICAL REQUIREMENTS / LIMITATIONS:

The geo-hydrological specialist study report, done as part of the site selection and licensing process, will assist the design engineer to determine the landfill depth which is one of the first parameters to determine when designing a new landfill. The MR2 require a minimum of 2m separation between the wet season groundwater level and the waste body. In the case of Class A landfills this means the top of the water table could almost be in the leachate leakage detection system due to the thickness of the layerworks (almost 1.5m). It is thus good practice to install a sub-soil drainage system underneath the layerworks to prevent water pressure from underneath the lining system until the overlying waste body is of sufficient thickness to counteract the underlying pressure. Also in deeper landfills like quarries the depth of the waste body and the resulting pressure from the waste's weight will force the groundwater level higher which makes the sub-soil drainage system a necessity to reduce the pressure on the overlying lining system.

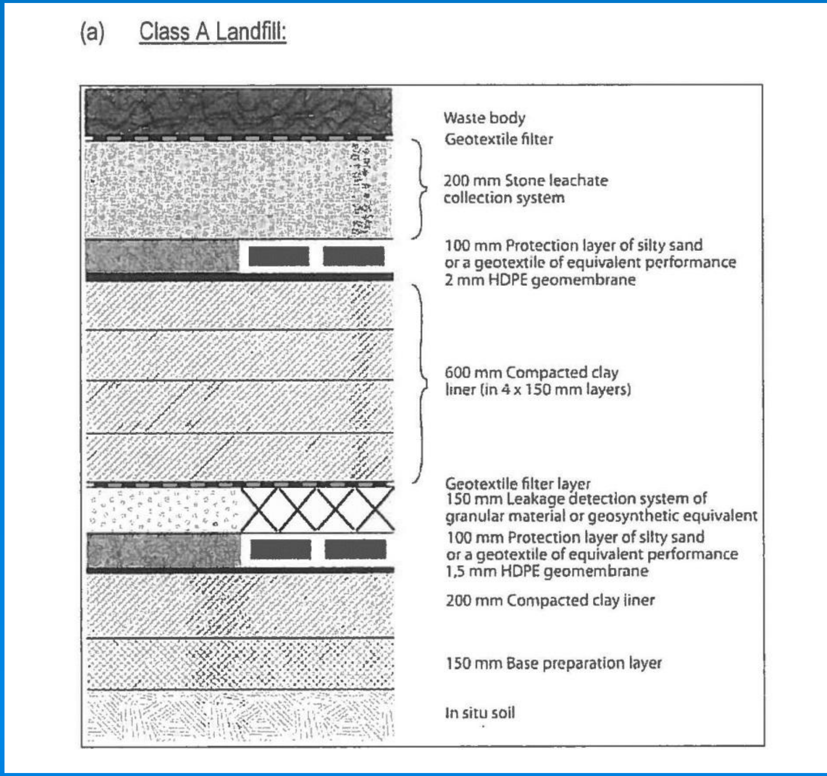
The outcome of the geotechnical specialist studies, done as part of the site selection and licensing process, will assist the designer with material selection for the landfill's lining system. In ideal circumstances the landfill will be situated in an area with suitable clayey *in-situ* material which is ideal for landfill construction. If the clay is of good quality it can be used in the lining works. Typically one would need clay with a permeability of 1×10^{-6} cm/s to 1×10^{-7} cm/s depending on the landfill classification. This permeability rate is also highly dependent on the compaction of the material together with the moisture content and plasticity index. These parameters must be confirmed prior to construction in a laboratory in order to confirm the material's suitability as construction material. This could make a huge difference in the construction costs, as well as the environmental acceptability of that area for a landfill site.

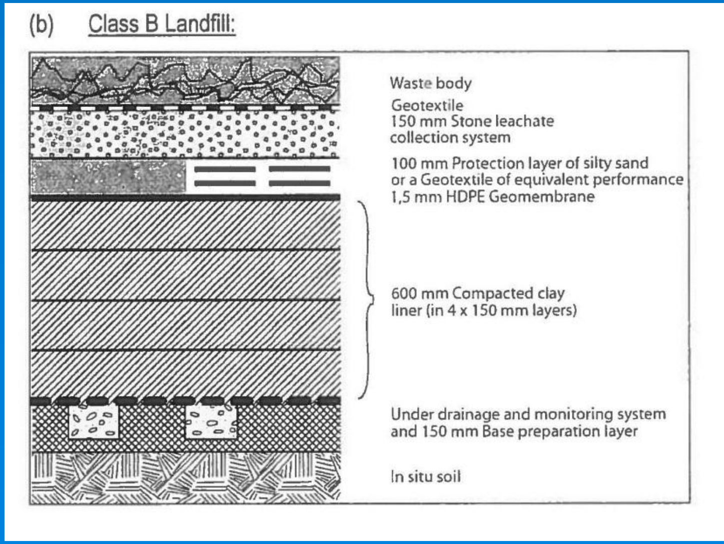
The geotechnical study would also determine if there might be clean sand available which could be used as the protection layer on top of the HDPE geomembrane and even as the leakage detection layer if the sand is of suitable quality and evenly grained.

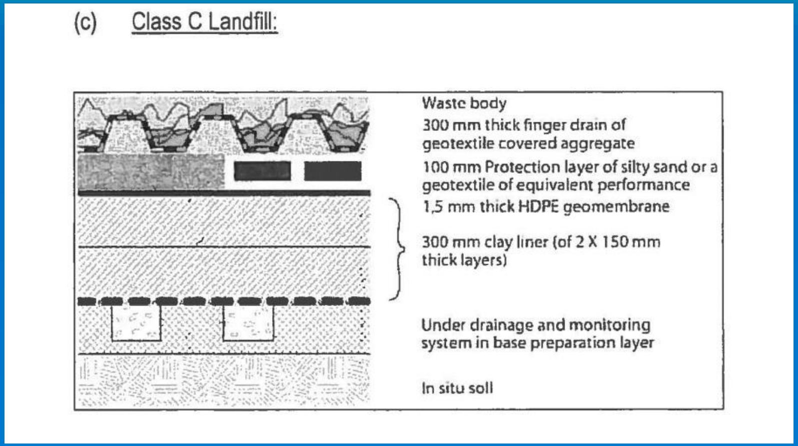
This investigation would also indicate whether there is sufficient material for daily covering of the waste for the life-cycle of that landfill site. Ideally there would also be sufficient available material within close proximity for the final capping of that landfill.

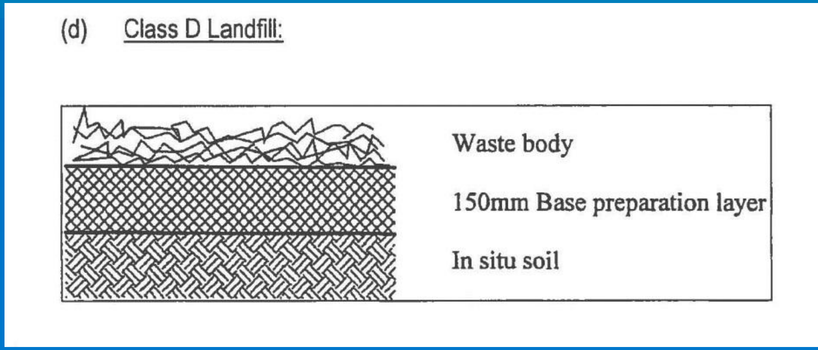
5. LINER MATERIAL SELECTION / AVAILABILITY / REQUIREMENTS:

As mentioned in the previous presentation the lining works for the new regulation classes can be summarized as follows:



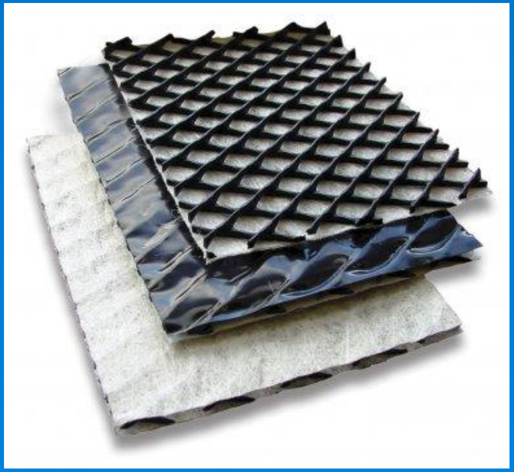






There are various alternatives to achieve the abovementioned lining requirements, which are dependant on material availability, costs, space saving, time saving and or other physical conditions. Most of these lining systems are based on the use of clay in the lining system but if there are either insufficient quantities of clay and / or substandard clay qualities the design engineer can look at alternatives like geosynthetic clay liners (GCL) or soil enhancement by mixing the available on-site material with bentonite or resins. The latter is a very expensive option and requires extensive lab testing to determine the required mixture to achieve the necessary permeability requirements and also involves strict construction quality assurance to ensure consistent mixing, moisturising and placing. Other factors such as compatibility with leachate and/or waste types must also be considered.

The leachate leakage and drainage systems are normally a granular medium but there are alternatives in the form of HDPE caspated sheets or geosynthetic drainage nets. In each case it is important to test the material's drainage performance under the load of the eventual waste body height, which could be as high as 50m.



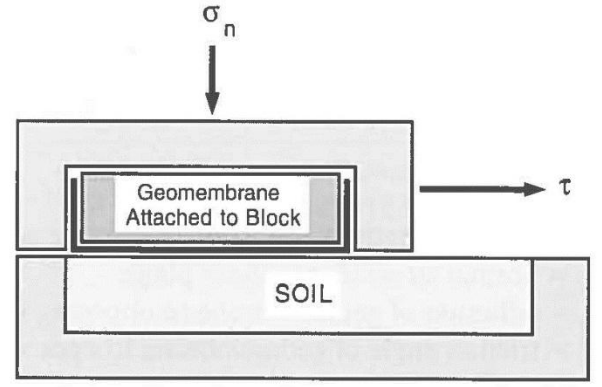
All the landfill classes except for Class D now require a leachate leakage detection system. This drainage system must be designed to intercept any leakage through the overlaying lining / barrier system. The detection collection system must be readily accessible and be easy to take samples from for monitoring purposes.

6. LABORATORY TESTING OF SITE SPECIFIC MATERIAL:

Although literature and estimated friction figures for various materials can give a good indication of the interface shear strength between the different lining systems, it is always recommended to do testing with on-site material as well as the actual lining material to be used.

The stability of the lining system and waste body during construction, initial filling and final landform level will depend on the weakest interface shear strength within the lining system and how this is affected by the driving and resisting forces. The use of geosynthetics introduces weak interfaces in the lining system.

Direct shear box testing of the different lining interphases under the calculated loads and angles are critical to ensure stability and prevent failure. The design engineer must design the layerworks envelope system as such that if a slip should occur, it should preferably happen on top of the primary liner in order to keep the liner intact. If shear box testing cannot be done then the engineer should err on the safe side by designing the basal side slopes flatter to 1:3.5 – 1:4. It is recommended that extensive shear box testing with on-site material be done on all the different interphases where any base liner side slopes are steeper than a 1:3 gradient.



(a) Direct shear test device

As mentioned previously the on-site clay should be tested in the lab to confirm if it will achieve the required permeability requirements during construction, at what optimal water content and at what compaction.

If on-site sand is used in the leachate leakage detection layer the grading should be tested to determine its drainage properties. It is advisable to do all tests with on-site leachate and if this is not available one must try and source a similar type of leachate. This is especially important in the case of GCL's. Studies have shown that little to no hydration has been achieved on GCL samples with some hazardous leachates. If this is the case, and no clay is available, one will have to look at pre-hydration of the GCL with water in order to achieve the GCL's specified permeability properties.

7. DESIGN CONSIDERATIONS:

During the design of a landfill one of the most important aspects is to avoid a head of the leachate over the lining system. The base of landfills should be graded to ensure gravitational free-flow into the main leachate drainage pipes. Slopes between 2 – 5% of a landfill cell floor are preferable. It is a good idea to rather reduce the spacing between the leachate drainage pipes (increase the amount of drainage pipes) in the stone drainage layer since it is a small portion of the cost compared to the rest of the works.

It is also recommended to install two drainage pipes alongside each other in the longitudinal direction in-case one becomes blocked.

The leachate drainage pipes must be tested to determine their deformation under the loads that will be experienced under the final landfill height. Pipes with sufficient side-wall strength are very important to ensure free flowing drainage for the site life of the landfill.

Pipe penetration through the HDPE geomembrane is also a critical element in landfill designing. By nature these penetrations are normally in the low point of a landfill and as a result would almost always be submerged under leachate. Due to the various linings to be penetrated and sealed this forms a very likely point for possible leakage. It is important to construct this on a solid base like concrete to minimize movement. The pipe should be prefabricated through a HDPE flange and cast into the concrete base and the lining is then battened onto the base and sealed with a capping strip.

Pipe penetration base

Battening of primary HDPE geomembrane to concrete pipe penetration base

Final capping strip extrusion welded over penetration

It is also good practice to design two low-points per cell (of similar depths) in case one low point becomes blocked. In deeper landfills it's very difficult to get to the low point for repairs once covered, so an additional outflow point is a good backup.

As mentioned previously it is important to consider the critical interphases of <u>all</u> the individual components in the lining system. The whole design should be based so that the primary liner system stays intact in the unfortunate event of a liner failure / slip.

When considering the different barrier systems for the different classes of landfill one should remember that these are guidelines with minimum requirements. The design engineer should still consider alternatives, especially with construction practicalities in mind. For example: The minimum thickness for the geomembrane protection layer is only a 100mm compacted sand for Class A, B and C landfills. Realistically, with the type of plant tracks used and the difficulty in detecting any damage of the geomembrane under the sand, it would be recommended to rather increase this thickness to 200mm of compacted sand. It is also advisable to place this layer early in the morning before sunrise when the geomembrane is still flat and without wrinkles. CQA during the placing of this sand protection layer is critical and the whole process must be witnessed by the CQA agent, but this will be covered in a forthcoming CQA presentation.

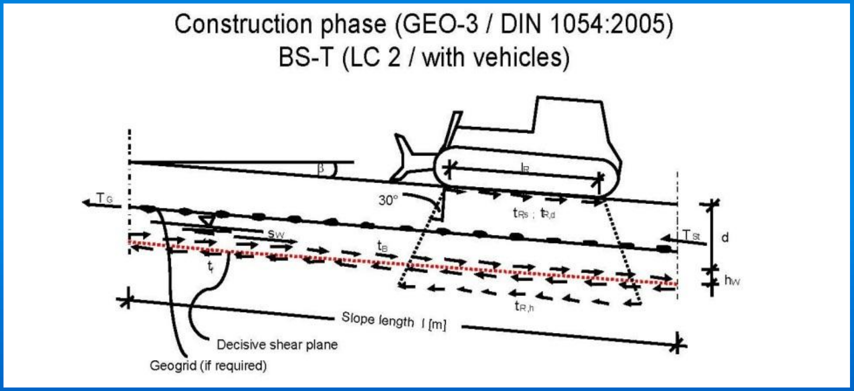
Preparing for early morning placement of sand protection layer

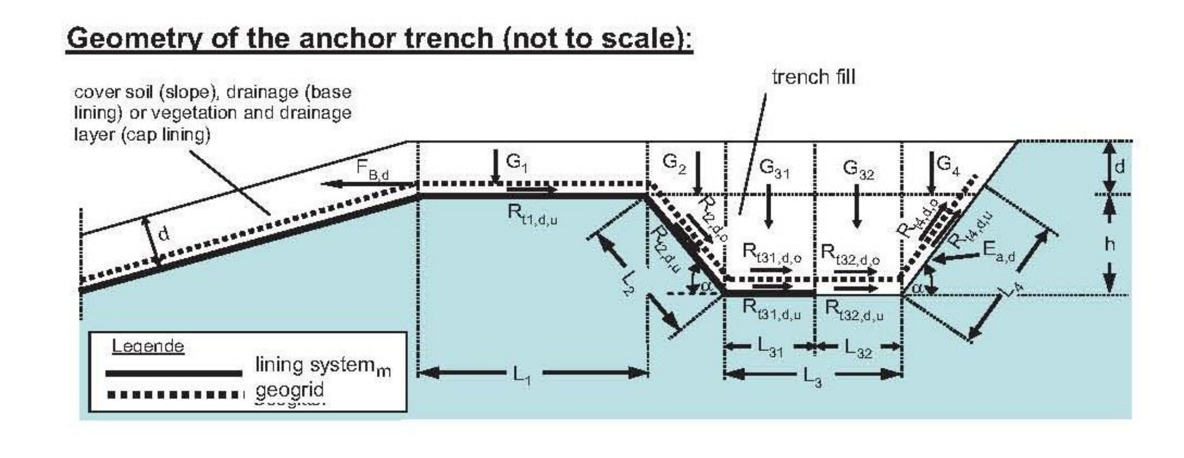
Note the smooth HDPE without wrinkles

Another design consideration would be the geomembrane protection on the side slopes (normally 1:3). It is difficult to place a sand protection layer on slopes in excess of 18 degrees since it would simply slide down the HDPE. A thick non-woven geotextile is normally used as an alternative for the protection of the HDPE on the side slopes, typically a geotextile of 1 000 – 1 500g/m² should be used but again it is a good idea to do lab testing to determine possible damage to the HDPE with the predicted load from the final waste body on the slope. The geotextile can also be used on the floor of the landfill if sand is not available or more expensive; the installation of the geotextile is by far more practical and quicker than placing a sand protection layer.

On the landfill side slopes the stone leachate drainage layer is normally placed directly on top of the protection geotextile, but on longer slopes the geotextile might tear under the load of the stone and a reinforcing grid must be installed to carry the load of the stone. The designer must specify that the stone be placed from the top to the bottom (pushed down the slope).

It is important to add all possible loads during the design of the reinforcing grid, not only the load of the stone, but also the weight of the construction plant that will place and level the overlying material.



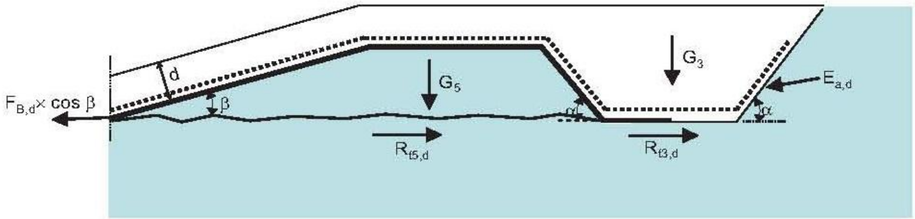


Anchor trenches must be designed to anchor the lining system without it slipping out or tearing. The anchor trench must be deep enough and its run-out length long enough to prevent the geomembrane from pulling out. It is advisable not to “over-anchor” the HDPE too tightly as a “slight release” within the anchor trench could prevent the tearing of the HDPE, which could result in a global slip.

For the latest Class A landfill liner requirements, a double composite lining system is required and therefore consideration must be given to the construction practicalities around anchoring two geomembranes separately. This may involve two separate anchor trenches which might be a problem if space is restricted.

The design should also provide the details of a double pipe penetration, where required.

Resistance against shearing of the anchor trench:



$$G_{5,d}\ [kN/m] = [(0{,}5*(h/\tan\beta)+L_1+0{,}5*(h/\tan\alpha))*h*\gamma_{Subsoil}] + [(h/\sin\beta)+L_1+(h/\tan\alpha))*d*\gamma_{Cover\ soil}]+[0{,}5*(h/\tan\alpha)*h*\gamma_{Fill\ material}]$$

When designing the anchor trench one must also ensure that the anchor trench does not shear in a horizontal plane, especially for deeper anchor trenches with shorter run-out lengths.

The design engineer can run different anchor trench configurations to determine the optimal usage of space and material, for example a deeper anchor trench with a thicker cover layer would reduce the run-out length required, if space is a problem.

Another addition to the latest lining regulations is the installation of a filter geotextile on top of the stone leachate drainage layer.

This is a very important addition to the lining envelope. This geotextile was not required in the MR2, which led to the clogging of the leachate collection layer, due to biological fouling, in many landfill sites that were constructed without this geotextile. The leachate drainage layer has an important function to ensure continuous free draining of leachate which in turn would reduce the hydraulic head on the primary liner and as a result minimize the potential of contaminant migration. Even if the geotextile clogs up, it would ensure that enough leachate is drained to prevent a hydraulic head to build up.

Stormwater / run-off water management:

Another important aspect of landfill design is the internal and external stormwater design. It is a minimum requirement to prevent clean run-off to come into contact with contaminated water and *vice versa*. External storm water channels must be constructed around the landfill to divert all upstream clean run-off around the site. If the landfill is designed to divert side slope run-off into a polluted storm water dam then these channels must be located along the toe of the landfill and have the required capacity to drain a 1:50 year storm in a 24 hour duration. All storm water drainage and containment structures must also have a 500mm freeboard.

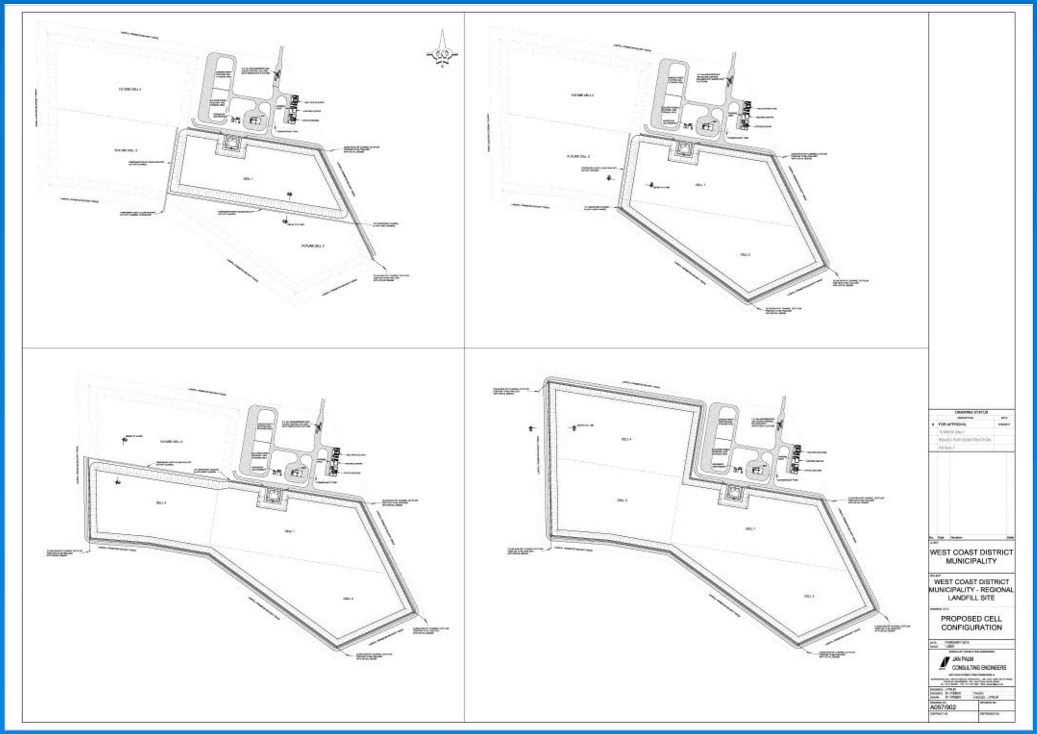
When sizing the capacity of the leachate storage dam and / or the contaminated run-off water dam it is important to make provision for the possibility that the dam might be full or near full in the event of recurrent rain events. A good rule of thumb is approximately 3 – 4 times the capacity required for a dam to accommodate the 1:50 year storm in a 24hour duration. Stormwater retention ponds are designed to mitigate the impact of a rapid flood event, but are not intended to store the uncontaminated stormwater.

Cover material:

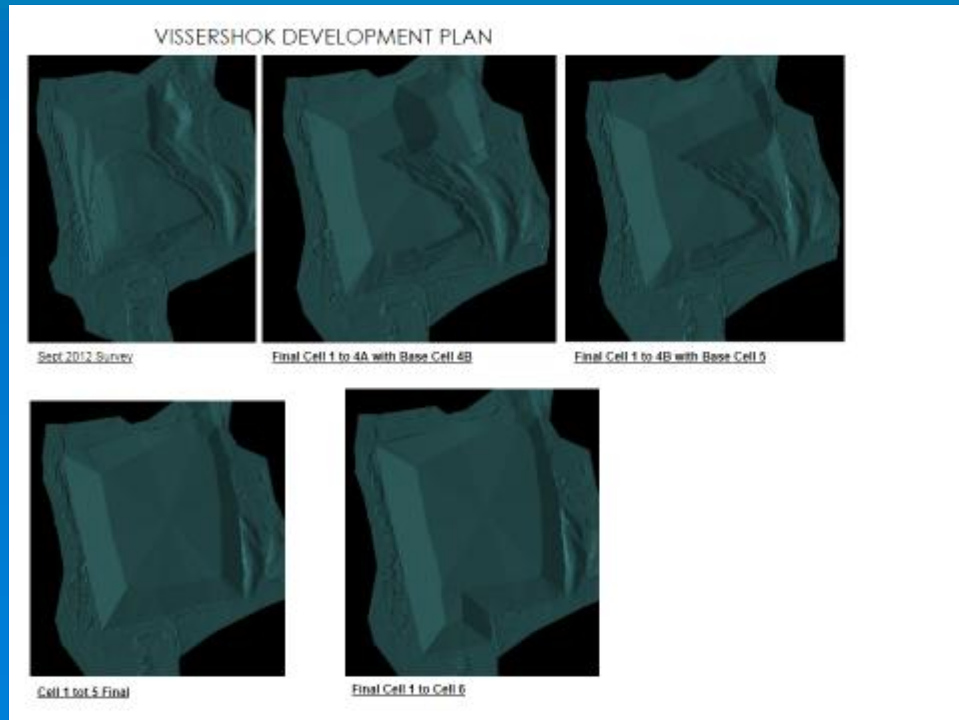
Waste must be covered daily to reduce odours, nuisance conditions, vermin, fires and scavengers. It would be ideal to obtain this material from or close to the site or even have this material stockpiled on site. However, if the material is too clayey, it may form horizontal impermeable layers or preferential flow paths that could surface on the side slopes of the landfill. The ideal cover materials are sandy soils or clean builders rubble, but this should be addressed in more detail in the operational presentation. For calculation purposes, approximately 17% of the total airspace could be taken up by the volume cover material required for the landfill, depending on the waste type and compaction.

Phasing:

As mentioned in the beginning it is important to have a good conceptual design that includes future phasing. The phases are typically 5 years apart, but should constantly be verified by the latest average disposal rates, usually of the last 6 months.



Typical phased layout drawing for the development of a landfill



3D Modelling of the existing landfill and future phases

Once the deposition rates have been verified by the weigh bridges, and compaction calculated using topographical surveys, future phases can be predicted using 3D modelling.

8. LIQUID MANAGEMENT:

Liquid could refer to uncontaminated stormwater runoff (no contact with waste); contaminated water run-off (from the working face) – previously discussed; or leachate (precipitation allowed to percolate through the waste).

Each site must have its own liquid management plan and design. Where possible, gravity systems should be designed that require no or minimum pumping. In some sites leachate collected can drain to sewer, in other instances this leachate or contaminated run-off water must first be collected and stored, before treatment, either on or off site. Storage facilities must be designed to contain all run-off / leachate within a 1 in a 50 year storm event and must be lined so not to contaminate the underlying substrate (leak). The design engineer must ensure that the site is equipped with the necessary mitigating measures in case some of the drainage and/ or storage facilities fail.

In the case of landfill draining into pump sumps it is important to protect the inside of the manholes by a HDPE membrane or similar, typically anchor knob sheets. As a result the concrete will be protected from chemical attack, increasing the sumps lifetime and reducing maintenance costs.

Concrete manhole ring with HDPE Anchor Knob sheet cast in

The pump sump or chamber should preferably be equipped with two pumps, one as a standby pump in case of failure of the primary pump. The pump chamber as well as pumps must also be designed to be able to accommodate all future phases to be linked to its “catchment area”.

Even where leachate drains directly to municipal sewer, it would be a good idea to design a backup storage facility for this leachate, in the event of a sewer blockage or other problem. Other means of handling leachate would be to drain or pump it into holding tanks and / or leachate lagoons and to tanker the leachate to sewage treatment plants. This could also cause problems in the case of shut down at these treatment plants or if they refuse the leachate load for whatever reason. This will then have a rollover effect on the landfill if the particular landfill is running close to its design co-disposal ratio since one will not have enough storage capacity to drain the landfill at the rate required. This could result in the pump sumps overflowing or leachate seeping out of the sides of the landfill.

On-site treatment of the leachate is expensive due to the relative small volumes of leachate, compared to a conventional sewage works. However, the advantages include saving tankering costs where the nearest municipal sewage work is far away, the treated sewage could replace clean water used for dust suppression, and the municipal sewage works can't be negatively affected by leachate loads.

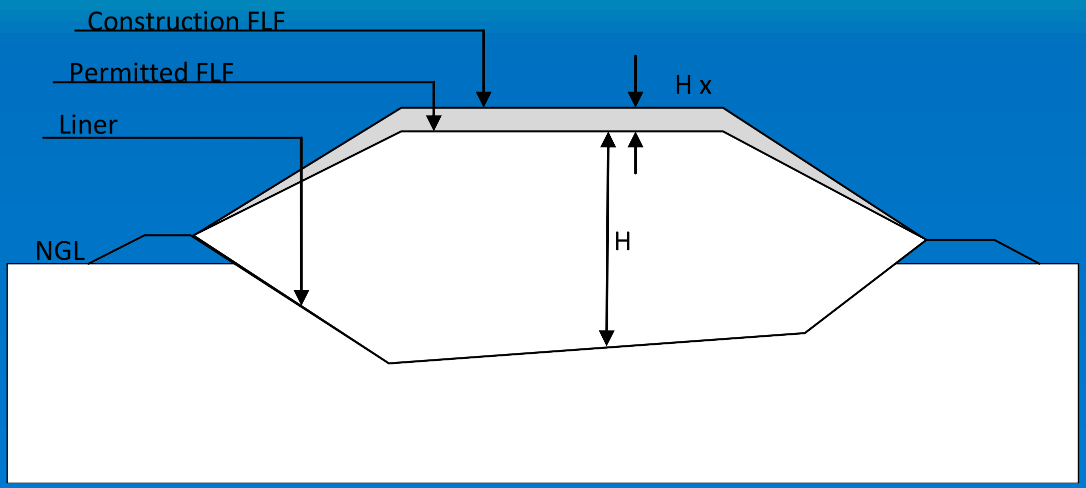
Leachate generation calculations are complicated and need to be verified by actual daily measurements.

9. SITE LIFETIME AND STABILITY:

Site lifetime determination is important for future planning. It can be determined in basically two ways:

Using estimated or weighbridge tonnages of the waste stream which must be converted to m^3 by assuming site specific compaction densities of the waste stream combined with cover material of approximately 17%. This is not a very accurate method.

The most accurate method is to do site surveys every month or at least 6 monthly and then calculate the difference in airspace consumed over a period of time using a DTM package like ModelMaker. This method then includes the compaction ratio, cover material, primary settlement and a portion of secondary settlement. By using the average of the last 6 months airspace consumption one can do a very accurate site life prediction of current and future cells.

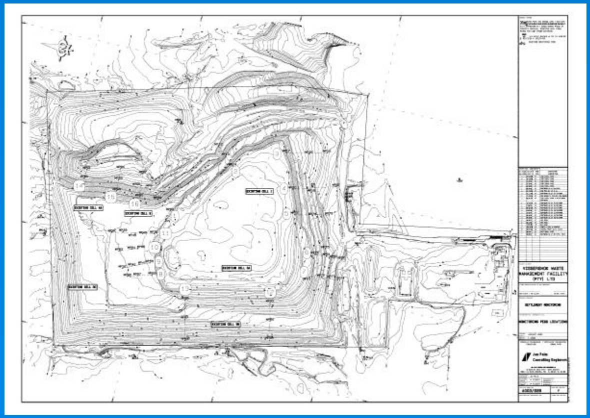


Normally all licenced or permitted landfills have a maximum height restriction which must be adhered to. Due to secondary settlement, a landfill could potentially be constructed a little higher than the maximum height and should settle over time to fall within the maximum height. By calculating the height that a landfill could settle and constructing the landfill to this “higher” final height the landfill owner / operator increases the site life and optimizes all available airspace. Secondary settlement can be as high as 15% of the waste body height (H), but a more conservative figure of 5 – 10% is suggested. The design engineer must also remember to make provision for the final capping layer thickness when he does the final landfill modelling. The maximum permitted height must include these capping layers.

Stability monitoring is required on co-disposal landfill sites as leachate build-up has a significant effect on waste body stability. This is exacerbated by the use of geosynthetic materials in landfill construction which typically have very low interface friction properties.

The first form of stability monitoring is visual inspection of the waste pile. This should be conducted by the operations team on site on a daily basis. Visual clues to be on the lookout for are: cracks developing on the waste slope, sloughing of waste/cover at the base of the slope and significant leachate seepage at the base of a slope.

All co-disposal landfills with a significant waste slope height (>5m) should have a stability survey monitoring network installed.



REHABILITATION REQUIREMENTS:

Landfill Rehabilitation and Gas Management does not form part of this presentation and will be covered in a future LIG seminar. Below are just a brief summary of the current regulated capping requirements as per the MR2