# Elstow Waste Transfer Station: the application of a geocell for building foundations on a landfill site

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ABSTRACT: With the continuing trend towards brownfield development, the requirement of Engineers to continue to explore new ways of solving foundation problems on very poor ground conditions is becoming more important. This Paper describes the development, design and construction of a geocell mattress foundation and building superstructure for a Waste Transfer and Materials Recycling Facility constructed on over 20 m depth of landfill on a site in Bedfordshire, England.

## 1 ELSTOW LANDFILL

Elstow Landfill site is located to the south of Bedford, which is approximately 60 miles north of London.

The contract to design, construct and operate a waste transfer station was put out to competitive tender by Bedfordshire County Council. Shanks and McEwan (Southern Waste Services) Ltd (now Shanks) were successful with their submission and the contract was awarded in January 1997.

The site at Elstow was due to reach the end of its use as a landfill site within the next year or so because it was almost full, and in order to maintain local waste collection services, alternative waste disposal arrangements were needed.

### 1.1 *Scheme Details*

The winning proposal put forward by Shanks was for a combined Waste Transfer Station and Material Recycling Facility capable of handling up to 180,000 tonnes per annum of household and commercial waste.

The scheme comprised a main portal framed building with a plan area of over 3000 m², with separate weighbridges, an administration building, messing facilities and paved access roads and storage areas. The overall cost of construction was approximately £2.6 million.

The transfer station is essentially a covered loading area, surrounded by concrete push walls, into which domestic waste is back tipped from refuse collection lorries. The waste is then loaded into articulated open lorries which enter and leave the building via a ramp which is 1.5 m lower than the adjacent loading area for ease of operation.

The main building also houses the Materials Recycling Facility which sorts the domestic and commercial waste, and bales the recyclable materials. The recycling equipment includes conveyors, magnetic separators, an enclosed main sorting line, manual baler and under-belt weighing device.

## 1.2 *The Site*

At the time when the scheme was designed, Elstow Landfill site was an active site operated for the County Council by a contractor. It lies about 4 km south of the centre of Bedford, immediately to the west of the A6 Wilstead Road and to the south of the Bedford Southern Bypass.

## 1.3 *Relevant History*

The site was first developed as a brick pit in the early 1920's and by the 1960's the excavation had extended to include the area immediately to the west of the A6 trunk road. When landfilling started this area was backfilled and regraded to form an access into the excavation. This area was identified as being the most suitable for siting the waste transfer facility because it minimised access road construction and was an area where site records indicated that the majority of fill at depth had been commercial waste, comprising predominantly builders rubble. This was overlain by several metres depth of domestic refuse. Part of the area had also been used by the landfill Contractor for vehicle servicing and parking with a service building, wheel wash and weighbridge.

## 1.4 *Geological Conditions*

Various site investigations records for the site were available. The most recent information was from a site investigation undertaken by Bedfordshire County Council in June 1996, to investigate the ground in the area identified as being the most suitable for siting the facility.

### 1.4.1 *Sequence of strata:*

At the time of tender ground levels in the development area varied from approximately 33.0 m to 40.0 m AOD.

1. Made Ground (Approx. 20 m to 24 m thickness). This appeared to consist mainly of domestic and industrial waste mixed with building wastes. Liquid wastes were also disposed of in lagoons of which eight had been identified. After the initial infilling, little waste appeared to have been placed until recent times when the site was landscaped with domestic waste and capped with clay. It was understood from the historical site information that the pits had been worked down to levels between about 20 m and 22 m AOD although unworked areas were present to higher levels. However, the later site investigation revealed that the made ground extended to a level of about 12.6 m and 15.6 m AOD.
2. Oxford Clay (Typical Thickness 4 m). Below the made ground Oxford Clay was encountered in some boreholes with only disturbed Oxford Clay identified in some areas.
3. Kellaways Sand (Typically 3 m to 4 m thickness). Poorly to well cemented fine sometimes clayey or shelly sands.
4. Kellaways Clay (Typically 1.0 m to 1.5 m thickness). Thinly laminated sometimes sandy, silty to slightly silty clay with scattered shells.
5. Cornbrash (Typically 1.0 m to 2.2 m thickness).Fossiliferous hard/dense/weak limestone with shelly, sandy or clayey layers.
6. Blisworth Clay (Typically 1.6 m thickness). This was encountered in some boreholes as a band of shelly silty clay.
7. Elstow Member (Typically 2.0 m thickness). Fossiliferous dense/hard/compact limestones with a variable shell content and containing bands of often shelly silty clay up to 30% of the total. The base was not always identified.
8. Blisworth Limestone (Typically 0.6 m thickness). Dense/hard/compact/weak limestones with a variable shell content.
9. Upper Estuarine Series**.** Where encountered, this consisted of interbedded sometimes shelly, thinly laminated silty clays, dense/hard/compact limestones and fine sand.

## 1.5 *Hydrogeological Conditions*

From the geological information, it was identified that three potential aquifers lay beneath the site. These were the Made Ground, the Kellaways Sand and the limestones in the Cornbrash, Elstow Member and Blisworth Limestone.

The Made Ground was believed to consist mainly of domestic, light industrial and other solid wastes, and various liquid wastes. It was anticipated that these deposits would contain groundwater perched on the underlying Oxford Clay which would have been contaminated by the wastes in the Made Ground and the liquid wastes. Slow seepage of leachate was observed at the base of the slope adjacent to a lake to the south east side of the site at about 23 m AOD. Initial monitoring from the gas wells indicated that the groundwater levels in the Made Ground were relatively high on the eastern side of the site but deepened to the west as the ground level rose.

The Kellaways Sand forms a regional aquifer and measures had been taken in recent years to minimise contamination by the groundwater in the Made Ground.

The lowest aquifers consisted of the Cornbrash, Elstow Member and Blisworth Limestone. They were separated from the Kellaways Sand above by the Kellaways Clay. It was considered that the Cornbrash, Elstow Member and Blisworth Limestone were likely to be in at least partial hydraulic continuity.

## 1.6 *Development of a Foundation Solution*

The ground conditions played a major part in the design and implementation of the proposals. The location of the facility was governed chiefly by the underlying ground conditions which favoured the area to the north west of the landfill site access.

The main problem with designing foundations on the site was due to the potential of very large settlement in the made ground.

The dynamics of settlement on non-engineered fill of this type is different from that experienced in other natural fills because of the nature of the material. Settlement as a consequence of degradation of constituent materials can induce both gradual volume loss due to compression and pore water migration, and collapse settlement as voids formed by containers such as old fridges corrode and fail. Settlement can also take place as a consequence of the additional vertical stress from the new construction works. These loads would result in both immediate and long term consolidation settlement in the pockets of poorly compacted cohesive material.

Trying to predict the amount of settlement that would occur over the 20 year life of the facility was very difficult. By analysing the site investigation results and with knowledge of the age of material (newspapers etc found in the trial pit arisings) and the way it was likely to have been placed, it was possible to make an estimate of the amount of settlement that remained. Shanks' experience with management of landfills was also very useful in this regard as they had records of time related surface deformations experienced on various landfill sites. Waste Management Paper No 26B "Landfill Design, Construction and Operational Practice", also provided useful general information. Based upon this information it was predicted that the area had the potential for up to 300 mm residual settlement.

The conventional engineering solution would have been to minimise settlement to sensitive parts of the scheme, such as buildings and plant foundations, by providing rigid piles. This solution had potential problems, however, due to the depth of unstable and variable made ground beneath the building and the potential lack of lateral support that could be offered to the piles. Potential problems of obstructions preventing or restricting pile construction was also a major concern, as all the boreholes had encountered obstructions. The potential for leachate to act detrimentally on the pile material, concrete or steel, was also of concern, especially since the historical records indicated that a wide variety of liquid wastes could have been deposited on the site in lagoons. There were also serious concerns that piles would have penetrated the Oxford Clay underneath the landfill, which could have resulted in leachate pollution of the underlying KellawaysSand which forms a regional aquifer.

During the tender period alternative foundation solutions were investigated including vibrocompaction, ground stabilisation and raft foundations. The main problem with all possible solutions was the variability of the ground. In particular the long term effects of negative skin friction on piles as a consequence of the degradation related settlement was very difficult to define and the reliability of slip coatings in this potentially very aggressive environment was not possible to quantify.

### 1.7 *Granular Mattress Foundation*

With all the foundation options considered there appeared to be potential problems. From an engineering and environmental standpoint it became obvious that the best way of avoiding problems associated with excavating and working in the considerable depths of landfill material was to develop a foundation solution that kept above it. Within Shank's team, the working relationship which had formed since first being introduced to the project was conducive for the development of an innovative solution, and the proposal to investigate if it was viable to utilise a geotextile reinforced soil raft was agreed.

The risk of building on the landfill materials still existed, in that potentially large settlements could be realised over the operational life of the facility. It was concluded that it would be possible to design the facility to tolerate total settlements of the magnitude predicted, which would mainly affect the elements that spanned the interface between the sections of the development constructed directly over the landfill, and those constructed on the ground outside the landfill area. These were drainage, service connections and road pavements, which although essential could be relatively easily monitored and adjusted or repaired if and when problems occurred during the working life of the facility. Tensar International were approached in January 1997, for advice upon the suitability of this type of foundation, and to see if they were interested in helping develop a solution. Their response was encouraging and it was decided to investigate if a Geocell Mattress could be utilised. The main advantage of the mattress was that it would be able to smooth out differential settlements between sensitive parts such as building foundations and mechanical plant conveyor bases. This would then be supplemented by an engineered facility on key structural elements so that they could be adjusted to tolerate some relative movement between foundations. The proposal was adopted enthusiastically and to ensure that the consequences of adopting this solution were appreciated by all the team, and acceptable to Shanks, a full risk assessment was prepared. Contingency measures were then included to allow for maintenance costs including the reconstruction of some floor slabs and drainage, and for some structural adjustments.

### 1.8 *Landfill Gas*

Prior to undertaking work on this project it was identified that one of the other main constraints with developing this site was that of dealing with landfill gases. Gas was already being extracted from the area of the proposed WTS as part of the landfill gas to power utilisation scheme. This gas was consistently above 45% v/v methane indicating that this area of the site was still very methanogenic.

For this scheme the whole of the raft under the footprint of the main building was covered by a continuous gas membrane. Below this an active gas extraction system was provided by specialists, which comprised a system of 63 mm diameter perforated pipes connected to an extraction manifold and an extraction pump. All gases removed by the system were then passed through the burner unit of the on site generating station.

### 1.9 *Design of the Facility*

The area of the development compound is approximately 210 m long and approximately 70 m wide with the long sides running parallel to the A6.

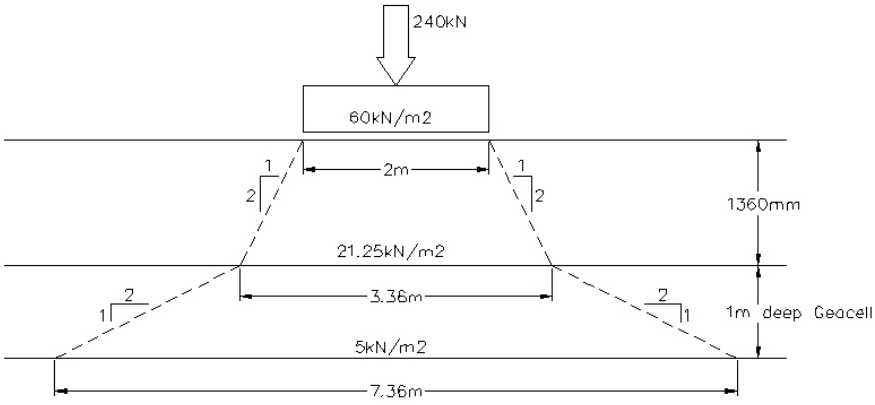


Figure 1. Plan of Waste Transfer Station facility

Before construction commenced, the existing ground in this area generally fell towards the A6. The highest part being in the western corner at an elevation of about 41 m AOD. Towards the south end of the site the direction of fall progressively changed to eastwards and south eastwards. The lowest part of the area was in the south eastern corner at an elevation of about 32 m AOD. Immediately to the south of the site the ground fell away quickly towards a lake.

From the site investigation information it became evident that, in the central area where it was proposed to construct the main building, below a level of approximately 27 m AOD the made ground was predominantly granular in nature. Directly above this to a level of about 31 m AOD, the waste was again predominantly light industrial waste with much brick and concrete, gravel and sand. Overlying this the fill contained more domestic waste and the clay cap that had been placed in the early 1970's. The maximum recorded leachate level was also at about 31.5 m AOD which, together with the positioning of the domestic waste, dictated the level of 31.0 m AOD as the lowest founding level for the geocell mattress.

The building substructure was therefore designed with the underside of the 1.0 m deep geocell raft foundation at a level of 31.1 m AOD. This gave adequate room for the geocell, the gas extraction system and membranes, and a pavement floor slab with a finished floor level of 34.2 m AOD.

With the raft constructed at this level it meant that at the north-west end of the main building, the area had been pre-surcharged by a significant depth (over 6 m) of fill material which had to be removed before the raft could be installed. At the southern end, although only 1.0 m of surcharge was removed, the area had been subjected to many years of live lorry loading, as this was where the contractor's lorry parking and servicing area had been sited.

The area surrounding the main building also incorporated geotextile reinforcement to help reduce the effects of differential settlement.

### 1.10 *Building Superstructure*

The Main Building is essentially a portal framed building just under 90 m in length and 31 to 36 m in width. The building is between 8.5 – 9.0 m high to eaves level from the ground and has a roof slope of 10°. The building is clad with a single skin of profiled metal sheeting, and has numerous roller shutter door openings. The frame is made up of a series of tied portals and associated bracing members. The building is founded on reinforced concrete pad foundations which in turn bear onto granular fill above the geocell mattress. The primary problems that the structural design of the building needed to address were those of total and differential settlements. This was done in two ways:

1. The geocell positioned beneath the footprint of the building was provided to smooth out differential settlement. The raft was designed by Tensar International and comprised cells of high strength geogrid filled with granular material which acts as a stiff member to resist differential settlement. As part of the construction process the raft was surcharged with material, to compact the granular material within the cells of the raft and to preload the landfill beneath the raft. In this way it was envisaged that immediate load related settlements would be avoided when the building was constructed, since at the level of the underside of the raft the temporary surcharge loading was designed to exceed the loading from the finished development. It was realised, however, that long term consolidation of landfill could still occur as could settlements due to degradation. If settlement of the building occurred uniformly this would not represent a problem to the building structure itself, although clearly, services would be affected. Differential settlements could occur however, if, for example, material in the landfill such as an old oil drum or fridge corroded and collapsed under the weight of overburden. In these circumstances the geocell would reduce the effects of differential settlement by spanning across any void that occurred below the raft.
2. The second way in which differential settlements were addressed in the structural design was by providing jacking points at each column of the building. As part of the operational maintenance it was agreed that throughout the 25 year life of the structure the building would be regularly monitored to identify any settlements of the foundations. If at any time there is evidence that a significant differential settlement problem has occurred, then the columns can be adjusted to re-level the building.

Figure 2. Photograph of the north-west end of Waste Transfer building

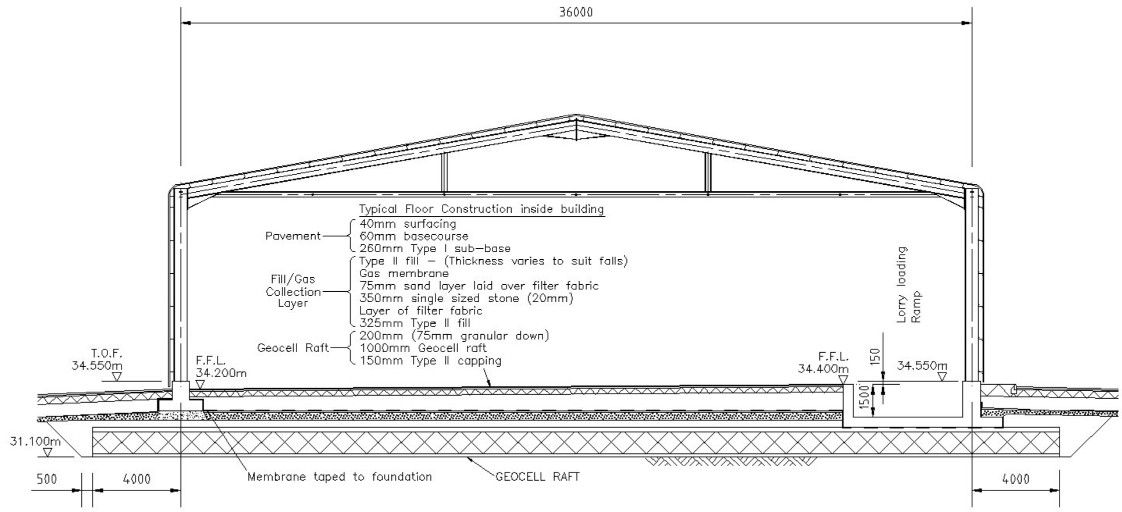


Figure 3. Typical section through building

## 1.11 *Geogrid Foundation Design*

The foundation mattress was required to transmit the imposed loads from the pad foundations, the ramp foundation and the loads on the internal floor, onto the existing foundation soils. These foundation soils comprised mixed waste materials that were well compacted as indicated by SPT values which were a minimum of 11 but generally above 20 indicating either a very dense cohesionless material or a very stiff cohesive material.

Whilst these tests indicated a firm foundation they were rapid tests and it was envisaged that the waste materials could continue to consolidate which would potentially have caused differential settlement, particularly if the imposed loads were uneven and non-uniform. To this end the geocell was surcharged to try to minimise any longer term effects by pre-consolidating the foundation materials.

The Geocell Mattress is a cellular construction formed of high strength HDPE geogrids filled with a granular material. This construction has been shown to provide a very stiff platform which can distribute loads and even out settlements, whilst retaining the flexibility to adapt to varying profiles. See Oliver, Younger, (1988).

The load distribution through granular layers reinforced with horizontal layers of a relatively low strength biaxial geogrid has been shown to be 45°. It is reasonable, therefore, to take the load distribution through the Geocell Mattress to be 1 vertical to 2 horizontal with the unreinforced fill above the mattress distributing the load at 2 vertical to 1 horizontal.

Whilst the actual pressure under the column pad foundations was trapezoidal a uniform pressure of 60 kN/m$^2$ was taken as the design value for this aspect of the design as the depth of both granular material and the geocell below the pad were a significant thickness to redistribute the loads.

Taking the standard pad foundation at 2 m$^2$ with a load of 60 kN/m$^2$ the load distribution was calculated as shown in Figure 4:

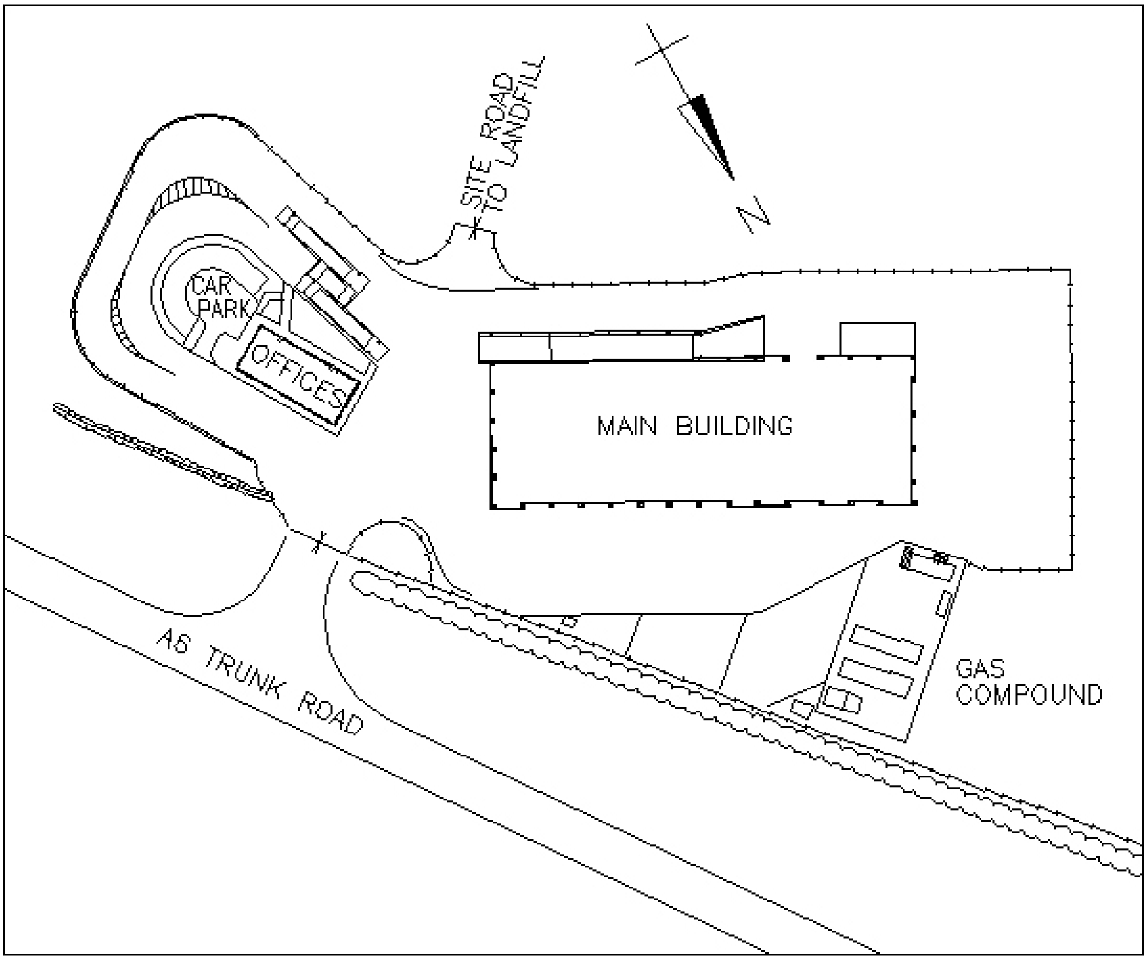


Figure 4

This arrangement therefore resulted in a nominal pressure increase due to the load from the pad foundation of 5 kN/m$^2$ which theoretically increased the pressure to 10 kN/m$^2$ where the areas of influence overlap. i.e. columns at 6.2 m centres with the area of influence 7.36 m$^2$.

The ramp area was considered separately as it has a combined column and slab arrangement from which the actual pressures will be less. As the slab level descends the loads from the fill material reduce thus reducing the effective pressure.

Hence the maximum differential pressure below the Geocell Mattress is 10 kN/m$^2$. If the Geocell Mattress was surcharged with 4 m of fill (approximately 80 kN/m$^2$) for a period of 4 weeks it was anticipated that the rate of settlement would reduce to a very small value and that the surcharge could then be removed to allow the full construction to take place. The surcharge represented an overload of approximately 2 on the final construction and therefore any potential residual load related settlements would be halved and therefore be very small.

The settlement profile of the Geocell Mattress was monitored during the surcharging operation to confirm that these proposals were correct.

The maximum vertical load applied to the Geocell Mattress was 80 kN/m$^2$. Assuming a limiting undrained shear strength in the foundation soils of 80/5.71 = 14 kN/m$^2$ the strength requirement of the Geocell as per the standard design method for Geocell mattresses under embankments was determined as follows:

See Jenner, Bush, Bassett, (1988).

$\sigma_h = \sigma_n - 2x$ Where $\sigma_n$ = vertical stress on the element and

$$x = \frac{2\sigma_n \sin^2\phi' \pm \left[4\sigma_n^2 \sin^4\phi' - 4\left(\sin^2\phi' - 1\right)\left(\sigma_n^2 \sin^2\phi' - \tau^2\right)\right]^{\frac{1}{2}}}{2\left(\sin^2\phi' - 1\right)} \qquad (1)$$

Where $\phi'$ = 35° $\tau = 14$ kN/m$^2$
Therefore $x$ = 18.5 kN/m$^2$
Hence $\sigma_h$ = 80 - 2 x 18.5 = 43 kN/m
The tensile strength of the Geocell should therefore be greater than 43 kN/m

A Geocell Mattress formed using Tensar SR110 diaphragms and a Tensar SS30 base has a tensile strength of (1 + 1/√2) x 45/1.1 =70 kN/m. Therefore OK.

It is common in the design of constructions over waste to consider the effect of a void appearing in the foundation. The 'rusty refrigerator' concept is described in Giroud, Bonaparte, Beech, Gross, (1990) and a design check was carried out assuming a 1 m diameter void appearing under the Geocell Mattress.

Taking the maximum pressure from 4 m of surcharge then we can use Equation 10 to give the load to be supported.

$$p = 2 \times \gamma \times r\left(1 - e^{\frac{-0.5H}{r}}\right) \qquad (2)$$

Where $\gamma = 20$ kN/m$^3$ , $r$ = 0.5 m and $H$ = 4 m.
Therefore $p$ = 2 x 20 x 0.5 ( 1 - 0.02) = 19.6 kN/m$^2$.

As the Geocell is stiff and we required it to remain stiff, a very low allowable strain of 0.25% was assumed giving a theoretically required tension of 19.6 x 0.5 x 4.18 = 41 kN/m.

The uniaxial grid is installed vertically in the Geocell construction and therefore the stiffness of the structure is much greater than when it is placed in horizontal layers. See Oliver, Younger, (1988). The Geocell as designed would therefore be adequate to span any reasonable sized void without showing the effect at the surface.

The final consideration regarding the use of polymer grid materials in this application is durability. The polymers from which the grids are manufactured are the most inert polymers to chemical and biological attack. HDPE, from which the uniaxial grids are made, is the polymer generally specified for landfill liner membranes and therefore the selection of this type of material is consistent with landfill technology.

Durability matters are covered by Wrigley (1987) and an example of the use of a Geocell Mattress in the support of a landfill liner over an old waste area in Germany is given in Tensar Division, Netlon Limited, (1989).

### 1.12 *Construction of the Facility*

The facility was designed and constructed in the period from January 1997 to August 1998.

This involved the excavation and reuse of over 10,000 m³ of clay capping, of which 2700 m³ was used to construct embankments and 7300 m³ was used to surcharge the geocell mattress. Approximately 23,000m³ of waste material was excavated and re-tipped further into the landfill, which was mostly cohesive and granular soils mixed with waste fragments.

The ground preparation included a 150 mm thick granular regulating layer which was laid as a capping underneath the raft, to separate the base fabric from the waste, and to provide a level platform on which to construct the geocell structure. The method of constructing the raft was prescribed by Tensar International in a standard construction sequence.

Over 12,000 m² of geogrid was used to form the mattress, 4400 m³ of 40 mm granite scalpings which complied with Tensar's specification was used to fill the geocell, and over 16,000 m³ of other granular materials were used to form the regulating layer, the protective capping and the protective layer for the gas extraction system.

The earthworks, excavation and construction of the geocell mattress element, including the capping and regulating layers cost approximately £320,000 to construct.

Table 1. Elemental Costs

| Item | Quantity | Rate £ | Total £ |
|---|---|---|---|
| *Earthworks* | | | |
| Excavate clay cap and store on site for use in embankments. | 2655 $m^3$ | 1.18 | 3132.90 |
| Ditto for use as surcharge. | 7159 $m^3$ | 1.18 | 8447.62 |
| Place and remove surcharge. | 6496 $m^3$ | 1.23 | 7990.00 |
| Excavate landfill and dispose in tip. | 23,152 $m^3$ | 1.34 | 31,023.68 |
| *Raft construction* | | | |
| 150 mm thick regulating layer. | 4400 $m^2$ | 3.48 | 15,312.00 |
| Netlon Geocell - install only. | 4400 $m^2$ | 1.33 | 5852.00 |
| Netlon Geocell - supply. | 4400 $m^2$ | 14.00 | 61,600.00 |
| Granular Fill to Geocell. | 4400 $m^2$ | 21.55 | 94,820.00 |
| 200 thick blinding 75 mm down. | 4400 $m^2$ | 4.64 | 20,416.00 |
| 325 thick granular bed. | 4400 $m^2$ | 7.32 | 32,208.00 |
| *Sundry items* | | | |
| Provision of stakes, ropes, settlement plates and supervision. | | | 10,034.56 |
| *Preliminaries* | | | 27,500.00 |
| | Total | | 318,336.76 |

Figure 5. Geocell raft during construction

The excavation and construction of the geocell took less than eight weeks to complete. The surcharge was then placed, and removed after a further four weeks, which took the overall construction period for the geocell to fifteen weeks.

During the excavation for the geocell foundation no unexpected problems were encountered. The contractor's method of working ensured that minimum areas of uncovered waste were exposed to reduce odours, and wet hessian was used to temporarily cap areas left exposed for any length of time. All excavators and plant had spark arrestors to reduce the possibility of igniting the waste or any gas pockets exposed during the works. The waste excavation was undertaken in accordance with Health and Safety Legislation concerning the moving and handling of this type of material.

### 1.13 *Settlement*

Using the site investigation information it was estimated that the area had the potential for up to 300 mm settlement over the lifetime of the facility. The expected settlement during the 4 week surcharge period being approximately 50% of the total. Settlement plates constructed at the base of the geogrid were levelled and recorded every day throughout the construction of the geogrid and then as the surcharge was placed and used to pre-load the area for the 4 week period.. An average settlement of 103 mm was recorded with a maximum 203 mm in the south–east corner.

Regular monitoring of the building column foundations has been ongoing since they were constructed. The monitoring is undertaken every three months, with the most recent readings taken on 25th April 2000. The average total settlement that has occurred at the column bases is 18.2 mm, with a maximum total settlement of 58 mm at the column foundation in the south-east corner of the building. It was originally envisaged that in total 4 to 5 settlement related structural adjustments would be needed at various stages through the operational life of the facility. To date no adjustments have been necessary.

## 2 CONCLUSION

The facility was commissioned in June 1999 and monitoring the stanchion bases continues. It must be appreciated that this type of foundation was only possible because a risk sharing approach was adopted by the Client/Operator and the Construction team. The Client (Shanks) is now committed to potentially higher maintenance costs for the facility as a result of adopting this type of foundation but benefited from significant cost savings at the time of construction compared to alternatives.


## ACKNOWLEDGEMENTS

| Geocell Design and Construction Team | | |
|---|---|---|
| Shanks and McEwan (Southern Waste Services ) Ltd | - | Client |
| Kvaerner Construction Ltd | - | Main Contractor |
| Buckingham Group Contracting | - | Earthworks and Substructure Contractor |
| Stirling Maynard and Partners Ltd | - | Civil and Structural Designers |
| Tensar International Ltd | - | Geocell Design and Supply |


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