Advanced engineered solutions using geocomposite drainage for fast consolidation in compacted fill

Nigel Robinson
Chartered Engineering Geologist, UK (pnjr@hotmail.co.uk)

Alan Bamforth
Managing Director of ABG Geosynthetics, UK (alan@abgltd.com)

Goran Erak
Director of Business Development, ABG Geosynthetics, UK (goran@abgltd.com)

ABSTRACT: Accelerated consolidation of the fill material is often considered to be a critical element on many civil engineering projects. Design engineers are often required to reduce consolidation time in order to meet demanding construction programs.

Ashton Moss is a commercial and leisure development near Manchester where large volume of fill material was used and fast consolidation was one of the critical design requirements. Total and differential settlement were the prime targets of this design. During design, various thicknesses of layers were considered to achieve the required rate of dissipation of pore water pressure from the fill material.

This paper explains the geosynthetic drainage technique that was chosen to provide drainage and reinforcement. In order to reduce surcharge heights and accelerate consolidation of the engineered fill comprising selected imported construction, demolition and excavation waste (CDEW), multiple geocomposite drainage layers were installed horizontally within the fill at one metre vertical spacing. Fildrain 7DD geocomposite drainage layer with double cuspated drainage core was used to maximize drainage input from the CDEW fill material and achieve the required rate of consolidation.

The analysis is important for designers who are considering innovative fill consolidation design solutions using geosynthetic alternative to traditional granular drainage layers.

Keywords: geocomposite drainage, fill consolidation

1 INTRODUCTION

Consolidation: In a contract, consolidation of fill is often a critical factor in laying earthworks for development in terms of time, and therefore cost and is particularly critical if there are tight schedules and/or penalties for late completion. This paper describes the benefits of a methodology utilising drainage geocomposite materials which was extremely successful, both technically and financially, but apparently has been rarely repeated.

The consolidation process requires the seepage of water away from the fill under imposed stress, whether it is self-weight (overburden stress) or increased stress imposed by surcharges. The time it takes is related to the permeability of the fill, the potential flow paths available to the water being expelled and upon the amount of stress imposed. Generally surcharges are used but surcharge mounds require large volumes of soil materials to be available and then moved regularly. This material is subjected to rainfall and can become unsuitable for later incorporation into the works and must eventually be removed from the site at significant cost.

In the past, earthworks contracts have occasionally used either vertical (band) drains installed after the fill is in place, together with a surcharge, or one or more horizontal layers of mineral drainage to accelerate the expelling of water. Vertical drains have commonly been geosynthetic for many years but were originally socks of sand. Both these methods improve the flow-path available to the expelled water but to be effective often need filter geosynthetics to prevent blocking by finer particles. The problem of both these methods is the time element. With the vertical band drains, the fill has to be constructed and then surcharged before substantial expelling of water starts. The horizontal sand/gravel drains improve the situation by starting to work as the layers are built up, but the layers are costly to construct, especially if geosynthetic filters have to be incorporated.

The use of horizontal geocomposites allows pre-formed and site specific designed drainage layers to be rolled out, taking minimal volume of the fill and at drastically reduced material cost and labour. Additionally, geocomposite drainage systems can allow the design of controlled flow paths for the expelled water, which may be essential for environmental management if the fill includes potentially contaminating matter.

The Contract: The site, situated on the edge of Ashton Moss, Ashton under Lyme near Manchester, had a brief to excavate a “mountain” of pre-tipped “inert waste”, which was far more varied than current specifications. This had been stockpiled on a partially excavated and backfilled site including some natural areas of peat. The waste soils were to be sorted to use the best for backfilling to a predetermined profile for a major retail and leisure development and ramps for a bridge over the Ashton North Bypass which was under construction. Performance standards were set in terms of minimum shear strength, overall settlement and for some areas very tight differential settlement. There were also significant contractual protocols for contamination assessment. The areas beneath the bypass had to be to Department of Transport specification and were to be approved by the Local Authority.

It was a very constrained site for such an operation but there was a suitable adjacent location to dispose of unsuitable waste. The timetable for the hand-over dates for the development were staged but most areas were already contractually agreed with others before this contract, and no time slippage was permissible so there were severe financial penalties for late delivery. As was common, the bypass timescale allowed for 6 months between completion of fill and the road construction phase to allow for settlement monitoring.

The Contractor had carried out previous work on the site which was partially completed but changes to ownership of the site led to termination of the previous contract and retendering with a significantly uprated specification and controls and a change of levels. The Contractor took on the Design and Construct contract at a fixed cost without realising the significant changes. He soon realised that a radical approach would be needed to avoid severe delay and significant losses.

2. GROUND INVESTIGATION AND GEOTECHNICAL SUMMARY

The stockpile contained approximately 350,000m^3 of imported "inert" Construction Demolition and Excavation Waste (CDEW). There was 200,000m^3 of existing structural fill and 500,000m^3 of excavation and the same of new fill required. This required about 750,000m^3 of soil movements without considering surcharges. The site was operated on a waste management exemption which was available under the legislation of the time.

A comprehensive ground investigation characterised the material available for fill and showed the fill previously laid needed to be improved using vertical band drains to meet the new contract specification and performance criteria. Also, due to changes in finished level, a wedge of New Fill had to be provided above the previous fill. Fortunately and very surprisingly, most of the stockpiled CDEW was usable, both from geotechnical and contamination viewpoints, due to the local knowledge of the Environmental Manager.

Geotechnical testing demonstrated a surprising consistency of the CDEW once the > 200mm size material and obvious unsuitable was removed. It separated into two classifications of a cohesive and granular type. However, most important, it was all too wet to compact adequately.

To summarise the fill: (CDEW to be used as New Fill)

Particle Size Distribution Gravel 30 to 70% Sand 20 to 40% Silt 9 to 30% Clay 2 to 17%	Compaction (4.5kg) Average Opt. Moisture Content 9.0% Average Dry Density 2.05 Mg/m3
Plasticity Indices PL 18-23% LL 32-52% PI 14-29%	Moisture Content Range 10 to 29% Mean 23% i.e. Much too wet to meet the Optimum Moisture Content above
Classification (using the Dept of Transport Specification for Highways Works) Close to the boundaries of : Class 1A – well graded granular Class 2C – stony cohesive	

Consolidation Tests

Critical so a large number of tests were carried out on each of the following:

- Undisturbed and disturbed samples of Existing Fill
- Samples of Proposed Fill compacted to specified density/moisture contents
- Material from initial constructed areas at 85/90/95% MDD/4.5kg tests
- As above but including up to permitted 5% organics

These were statistically checked and m_v and c_v at 95% confidence levels were calculated. From these reasonable "realistic anticipated" settlement could be calculated

Much of the oldest fill requiring excavation was unsuitable as it was mixed with peat and some of the softer soils including laminated clays. The whole area was under laid by glacial till.

3. DESIGN REQUIREMENTS

The main geotechnical performance elements of the Employer's Acceptance Criteria were:

"Design and construct earthworks …so as to provide a finished formation which within six months after completion of filling shall support ground bearing floor slabs with individual gross floor areas of up to 15,000m2 with….

- …a maximum ground loading intensity of 27kPa, in some areas 20kPa
- …limit total settlement of the floor slabs to a maximum of 25mm at end of six months after completion of their construction
- …shall limit further settlement to 10mm after a further six month period.
- …Maximum slab differential settlement shall not exceed 1 in 700
- …Parking areas required a minimum CBR of 2% plus the same settlement criteria as above.

Previous Phase A/1 already had Existing Fill placed at least a year and a half before and it was further consolidated using 7,500 vertical band drains.

Whilst the gross loadings for the new phase were quite low, the settlement criteria was more difficult to achieve and to meet the programme, work had to continue through several wet winters.

To a significant extent, the Contract phasing determined the timing and therefore the design/construction methods available for the consolidation of the New Fill.

4. CONSIDERED DESIGN TECHNIQUES

The New Fill was to comprise CDEW and was to be placed over the remainder of the site following excavation to the top of the glacial till. The depth of New Fill varied between about 4 metres and 7 metres.

Design considerations included:

- The method would need to cope with wet fill
- Construction was needed through winter and wet weather
- The need to construct large or small areas dependent on the predicted weather to minimise risk of ruining good fill.
- Minimise a surcharge due to cost and time to place and remove – and it becomes waterlogged with time.
- Provide confidence that it will meet the performance specification.
- To obtain Tameside Borough Council's Engineer's acceptance for construction of the Ashton North Bypass.

Techniques considered:

4.1. Lime Stabilization

Not ideal on such a constrained site with a high organic content. This needed time for trials.

4.2. Horizontal Drainage in the Fill

The time for substantial consolidation settlement was the main issue. This is calculated by the equation:

$$t = T_v.\ h^2/c_v$$

Where: T_v = Time factor; c_v = Coefficient of consolidation

Note that h, the drainage path (or layer thickness) is the only potential variable and is squared. Take a 5m layer of fill draining top and bottom h, the drainage path is half (draining top and bottom) = 2.5m then h^2 =6.25. If the layers between drainage are reduced to 1m h=0.5 and h^2=0.25. That reduces the time by a factor of 25. Horizontal drainage installed as the new fill was placed therefore seemed the best way to reduce the time.

A variety of layer thicknesses were modelled using min m_v/max c_v; mean m_v/mean c_v and max m_v/min c_v parameters to give best credible, most probable and worst credible settlement times. Differential settlements were also calculated.

Traditional methods would use horizontal layers of drainage stone to collect and remove pore water from the fill material. Installation of drainage stone layers, typically between two layers of filter fabric, is time consuming.

Initially the contractor wanted to use traditional drainage but the problem of constructing a thin gravel layer is practical. It needs to be placed in thin layers to minimise costs of expensive gravel. However, using a machine then damages the underlying geotextile used as a filter/separation layer if the gravel layer is too thin to spread the load of the machine.

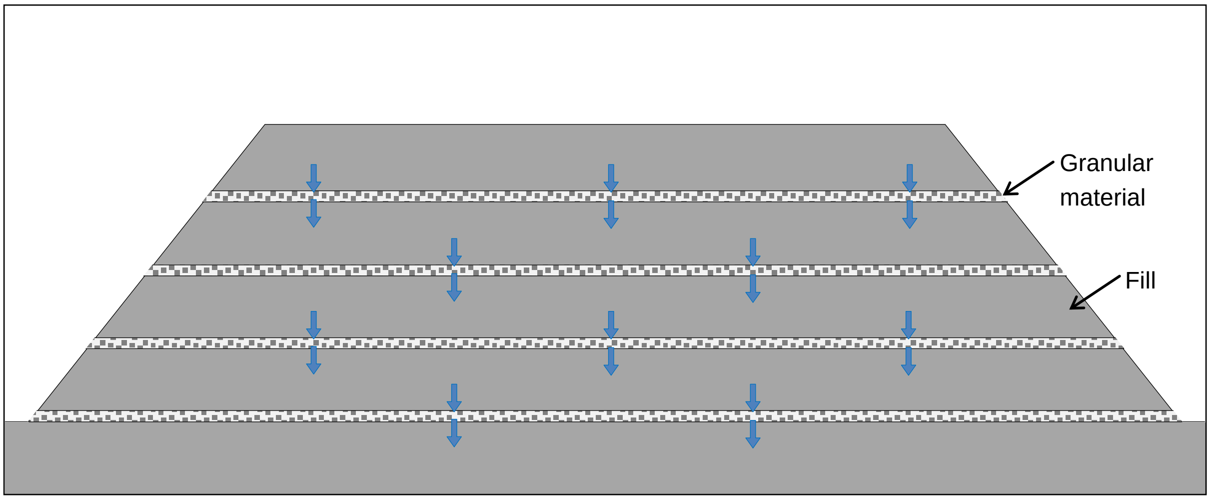


Figure 1 – Layers of granular material allowing rainfall and collected water to penetrate the material below

A granular stone layer is permeable in horizontal and vertical direction and collected water is adding a hydraulic head onto the fill material below (Figure 1). This is extending the time required for the fill consolidation and therefore increasing the cost of construction.

Analysis of multi-layered soil consolidation have shown that this process can be accelerated by using horizontal layers incorporating an impermeable membrane to control vertical movement of the water, restrict the ingress of rainfall and reduce the water head within the drainage layer (Barry and Van Der Bend 2006).

4.3. Change to Geocomposite Drainage

It was necessary to find a more advanced consolidation method that would accelerate consolidation and provide more effective drainage performance in order to reduce cost.

Geocomposite drainage layer was considered as a potential adequate and cost-effective design solution. It was established that geocomposite with specific composition and performance was required to achieve all design requirements and reduce the cost of construction.

- Calculations suggested complete consolidation would be in the order of six weeks rather than typical six months or so with a drainage layer top and bottom.
- With such a short timescale even a 50% over-run would be acceptable, so this reduced risk of not meeting phase delivery.

5. GEOCOMPOSITE DESIGN SOLUTION

Geocomposite drainage layers are widely used in all civil engineering applications. Various products are available with huge difference in the composition and performance of the geocomposite. Some geocomposites are specifically designed and developed for particular applications (drainage, gas venting, capillary break, capping, reinforcement or fill consolidation). It is essential to select a suitable geocomposite to meet specific design requirements for each application.

It is particularly important to understand what flow capacity can be expected to be achieved and ensure that in-plane flow tests are done according to the EN ISO12958 standard test using soft platens to simulate the effect of backfill material (Robinson and Erak 2014).

The predicted 120mm of consolidation of the 5m high fill is equivalent to a water discharge of 24 litre/m^2 or approximately 4.8 litre/m^2 per layer. The interface shear strength between the geocomposite and the fill was not critical on this project otherwise shear box test would have been required.

A geocomposite drainage layer accelerates fill consolidation by shortening the drainage path and providing high horizontal drainage capacity. Consolidation also results in the strength gain within the fill.

A specific type of geocomposite with vertically impermeable central core and drainage void on both sides was required to prevent saturation of the fill below, reduce the required consolidation time and provide a cost saving solution. Combined effect of high flow capacity with vertically impermeable drainage core results in rapid lateral dissipation of pore water and accelerated fill consolidation (Figure 2).

Geocomposite with vertically impermeable core was also required to provide a barrier for the capillary water and prevent any vertical migration of potential contamination within the fill material.

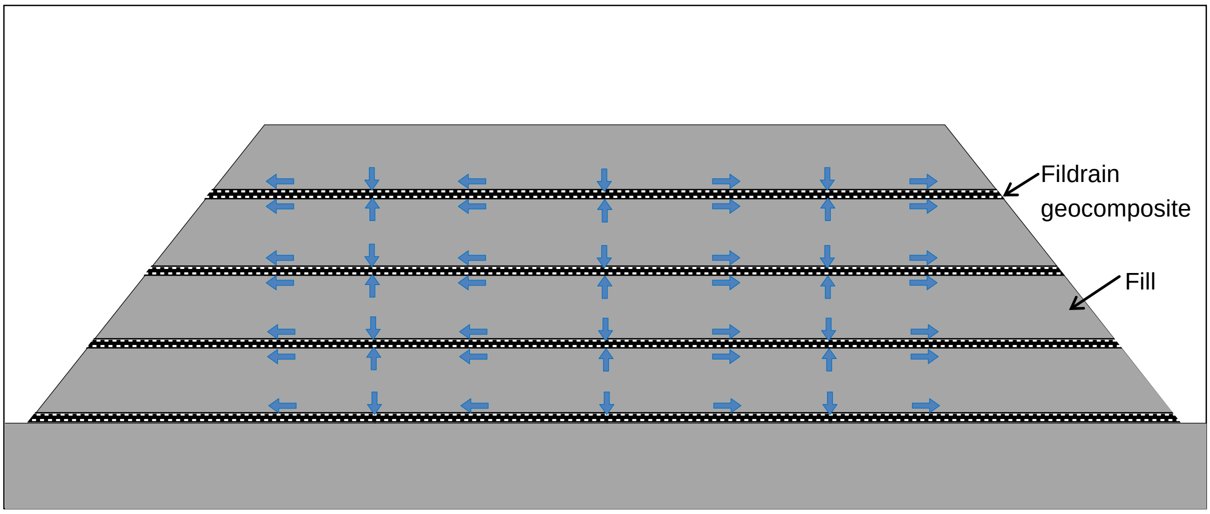


Figure 2 – Fildrain 7DD geocomposite drainage, barrier and reinforcement layer

A trial area using a geocomposite drain with one metre nominal thickness fill layers was quickly constructed and the advantages found were:

- Dramatic reduction in surcharge loads was possible – often only two metres was placed. This greatly reduced material handling costs and speeded up final preparations for delivery of the phases.
- Observation showed that having these regular layers allowed drainage to take place as the fill was being constructed. Water was visibly draining through the thin geocomposite in lower layers as the upper layers were still being constructed.
- Having these layers and a flexible geocomposite material also allowed the flow of this drained water to be directed towards sumps where it could be checked for contamination and disposed of quickly and efficiently rather than saturating the lower levels of the fill.
- Small areas or cells could be constructed so minimizing risk in poor weather and the drainage of expelled water was controllable.
- Tameside's Borough Engineer was appreciative of the visible expelling of water from the fill.
- The same geocomposite was also used beneath the surcharges to make it easy to clean off the surcharge from the fill.

In addition, tensile strength of the geocomposite drainage layer provided some element of reinforcement that enhances the effect of drainage and improves the consolidation process by incorporating semi stiff layers.

Therefore, strength gain and accelerated fill consolidation is associated with the interaction of adequate dissipation of the pore water pressure, effective horizontal barrier and the reinforcement.

6. GEOCOMPOSITE – SPECIFIC FILL CONSOLIDATION FEATURES

Geocomposite with specific composition and performance characteristics was crucial part of this geotechnical design. Fildrain 7DD geocomposite was selected to provide the required performance for this fill consolidation application.

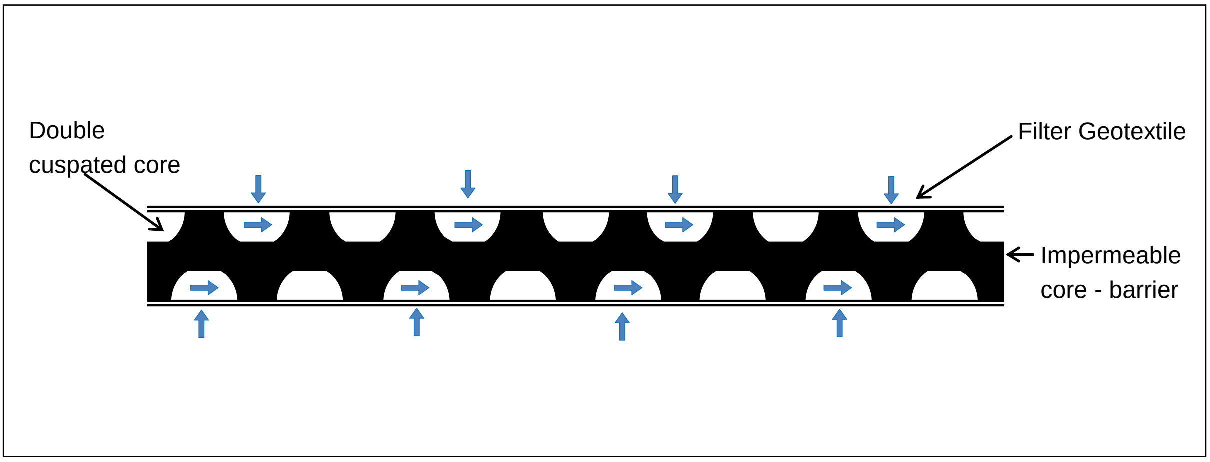


Figure 3 – Geocomposite drainage layer composition – Double cuspated drainage core provides an impermeable barrier with drainage void on both sides.

This is a geocomposite drainage layer comprising a double cuspated HDPE drainage core with geotextile filters thermally bonded on both sides (Figure 3). The product is horizontally permeable on both sides but central core is impermeable vertically and acts as an effective barrier.

It is imperative that geocomposite has adequate flow capacity and a composition that allows efficient evacuation of the collected water in horizontal direction. It has sufficient puncture resistance and tensile strength to withstand compaction of the backfill material and provide effective reinforcement.

Fildrain 7DD geocomposite unique composition provided all three elements required for this installation: drainage, barrier and reinforcement. It also incorporated necessary filtration performance. This is a geocomposite drainage layer with specific features designed for fill consolidation (Figure 4).

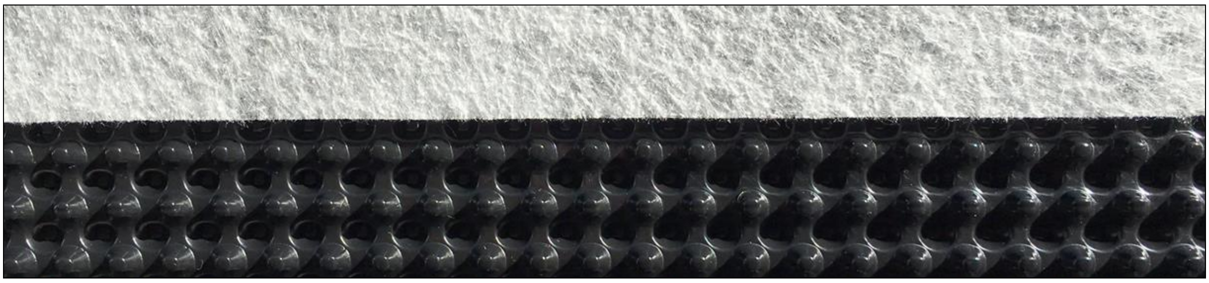
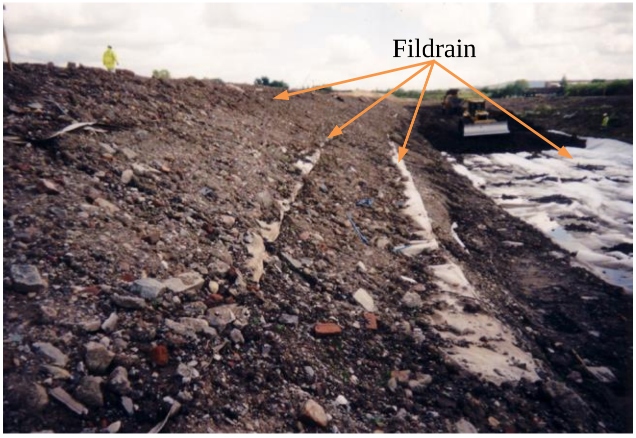


Figure 4 – Geocomposite drainage layer

7. GEOCOMPOSITE INSTALLATION

The geocomposite was supplied on 4.4m x 80m rolls and installed at 1.0m vertical spacing and nominal gradient of 0.5%. Fill material was placed in 500mm layers and adequate compaction of the wet fill was achieved using only bulldozer operations.



Min. 200mm thickness of the backfill material was maintained on top of the geocomposite for all construction traffic. High drainage performance of the geocomposite was evident from the discharging volume during construction. Water collected in the geocomposite was discharged into sumps and removed continuously to prevent saturation of the lower fill formations. Total height of the placed fill material was between 4 and 7m.

After completion of the earthworks, the steel building structure was supported on piles driven through the fill. The ground beams, floor slabs and car park areas were constructed directly on the fill.

Post construction survey showed no settlements on any part of this site.

8. GEOTECHNICAL MONITORING AND PERFORMANCE ASSESMENT

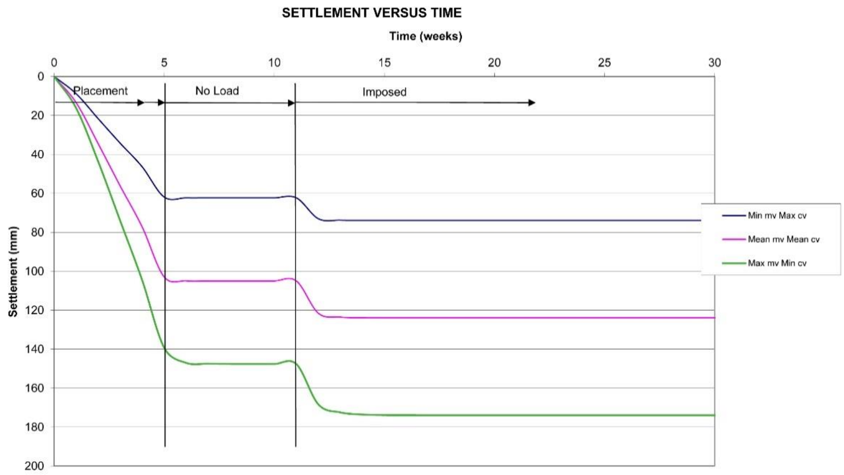
From a large number of consolidation test data, estimates were made on the rate and extent of settlement varying;

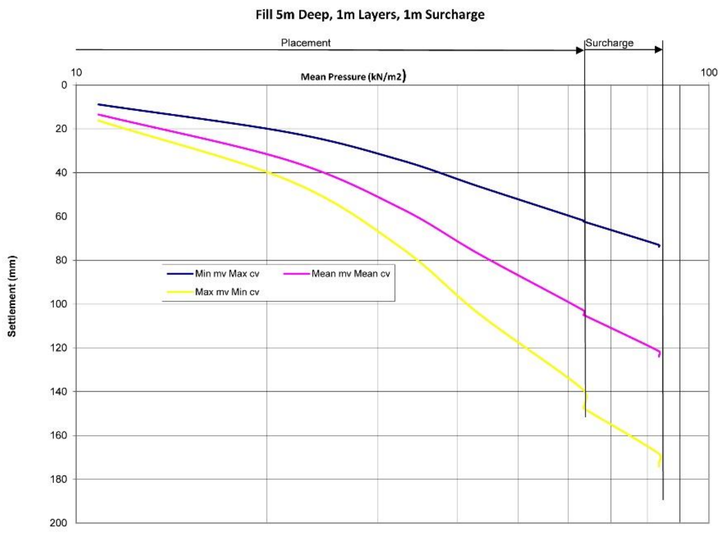
- layer thicknesses/number of drainage layers,
- thicknesses of fill
- variety of surcharge loads.

Each model was calculated using minimum m_v and max c_v; mean m_v and mean c_v; and maximum m_v and minimum c_v. This was aimed to give a realistic range of likely results.

These informed us of the time constraints for each option and allowed choice of technique for an area. This was variable on the anticipated weather/seasonal conditions and time available. Obviously a conservative allowance was made and initially a large amount of settlement monitoring was carried out but with time, confidence was built which allowed this to be reduced somewhat. The main outcome was the insertion of the geocomposite drains gave predictable drainage allowing very short surcharge periods with very low surcharge mass.

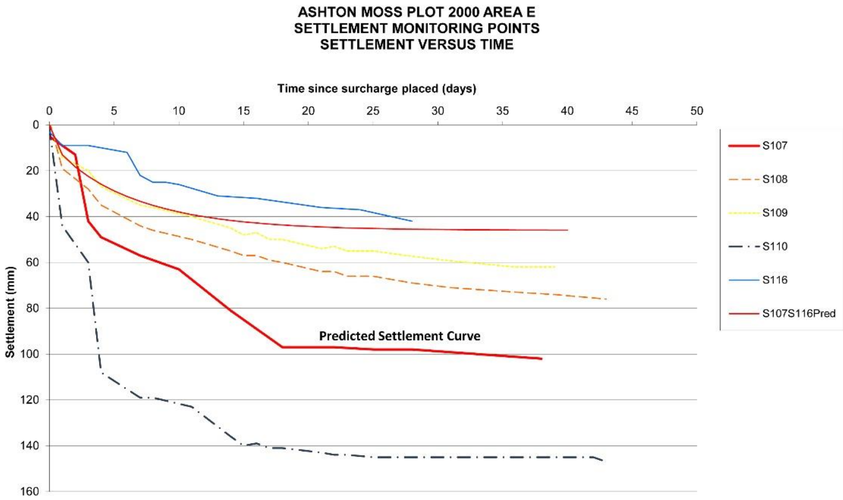
Trials were carried out to build up confidence that the testing and calculations were of the correct order. Other than the normal geotechnical properties testing these were settlement monitoring using sleeved pins through the fill.





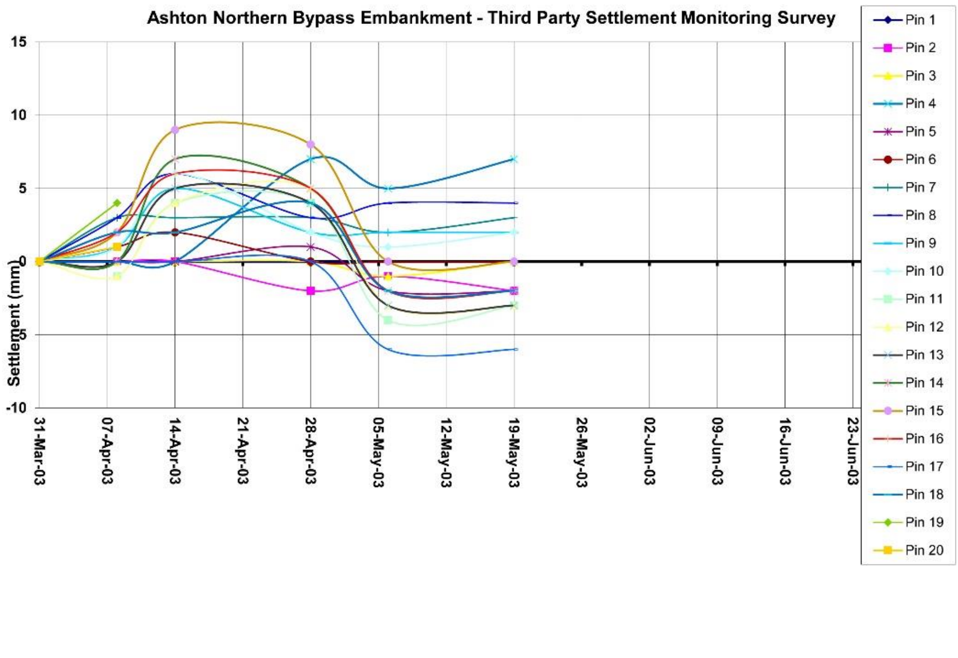
These settlement measurements proved that the calculations were largely correct, some slight differences were encountered in terms of the total settlement but the rate of settlement was only a few weeks rather than months.

The technique was initially checked in an area which was not time critical but was soon adopted across the whole works and particularly during the first winter which was exceptionally wet. Again using this technique, fill that would have been traditionally far too wet to consider was used and whilst total settlement was high the time to consolidate was within the predicted bounds. Below is a typical set of results for a small area of fill.



The highest risk on the contract was the ramp for the Ashton North Bypass. This was to be constructed under a separate contract by another contractor and under supervision of another consultant. They were skeptical, as were some of the Engineers from the local authority who had not signed off the methodology. As soon as this area was handed over they requested a third party geotechnical engineer to monitor the zone.

It was intensively monitored over three months and proved there was minimal settlement and well within the limits required by the Contract Specification. The initial results are presented below showing minimal further settlement and the positive readings were due to the response of the unloading of the shallow surcharge (1.5 metres).



9. CONCLUSION

Accelerated consolidation of the extremely wet fill material was one of the critical design requirements on this project. In order to reduce consolidation time and meet the demanding construction program it was necessary to consider a geocomposite drainage layer with specific features designed for fill consolidation.

A particular type of geocomposite with vertically impermeable central core and drainage void on both sides was required to prevent saturation of the fill below, reduce the required consolidation time and provide cost saving solution. This combined effect of high flow capacity with vertically impermeable drainage core was needed to achieve rapid dissipation and removal of pore water and faster consolidation.

Fildrain 7DD geocomposite drainage layer with double cuspated drainage core was used to achieve the required rate of consolidation. Multiple geocomposite layers were installed horizontally within the fill at one metre vertical spacing. The geocomposite composition provided all three elements required for this installation: drainage, barrier and reinforcement.

Adequate site trials were carried out to ensure the selected geocomposite was compatible with the fill material and construction method. Total of 700,000 cubic metres of the fill material were installed within the available time and the required rate of consolidation was achieved. The new retail park was completed on time and within the specified settlement parameters.

This project demonstrates how innovative fill consolidation design solutions can be achieved using geosynthetic alternative to traditional granular drainage layers.

10. SUMMARY

Design considerations summary for the accelerated and cost effective fill consolidation:

- Specify appropriate construction method for the site specific fill material and required consolidation time.
- Calculate optimum vertical spacing between horizontal geocomposite drainage layers within the fill material.
- Carry out site specific trials to confirm calculated consolidation time and selected construction method.
- Use geocomposite drainage layer with specific features designed for accelerated fill consolidation.
- Consider double cuspated geocomposites with impermeable central core and drainage void on both sides to reduce consolidation time.
- Use geocomposite with equal flow capacity in long and cross direction to ensure adequate drainage performance and allow fast installation of the fill material.
- Check the geocomposite data sheet for appropriate flow characteristics under appropriate boundary (soft platen) conditions.
- Specify minimum layer thickness and compaction method for the placement of the fill.
- In order to prevent saturation of the lower fill formations, adequate pumping capacity is required to remove water discharging from the geocomposite.

- Ensure that filtering performance of the geocomposite geotextile is compatible with selected fill material.

REFERENCES

Robinson N and Erak G (2014) "Standard In-Plane Flow capacity Test and Effects on Slope Stability", Ground Engineering 2014.

BS EN ISO 12958: 2010. Geotextile and geotextile related products-determination of water flow capacity in their plane.

Barry AJ and Van Der Bend (2006) "The efficiency of drainage blankets in surcharging of soft clays", Ground Engineering 2006.