THE FINANCIAL AND ENVIRONMENTAL ECONOMIC REDEVELOPMENT OF A SCRAPYARD AND COLLIERY SITE THROUGH THE COMBINED USE OF GEOSYNTHETIC SLOPES AND WALLS

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Abstract: Areas which have historically been situated on the outskirts of major conurbations have frequently been 'zoned' for less popular industries. With time, these sites are coming under increasing pressure to be absorbed into the sprawling mass of the conurbation itself.

One such site is situated in Mapperley in Nottingham. Historically the site was used as a repository for colliery spoil (7m - 8m) from the nearby Gedling Colliery. After this, from the early seventies, the site was used as a lorry breakers and scrap yard until its purchase in 2005 for redevelopment into residential use.

After a feasibility study, it was ascertained that the existing slopes, created from the land raising exercise, would be unstable in the long term and unable to withstand the additional loading from the development.

It was proposed to utilise Reinforced Soil Walls (RSW) and Mechanically Stabilised Earth Slopes (MSEW), up to 8m high, to retain the developable area. Predominantly the site will utilise RSWs, however, in areas where adoptable highways are planned, then MSEWs would be utilised. All slopes and walls have been designed to have 'green' faces.

The main reason for the approach using geosynthetics is that it allowed the reuse of the colliery spoil (which was also contaminated with hydrocarbons) in the construction of the slopes and walls rather than exporting and importing materials to site.

One other benefit of this approach is that it allowed construction of houses and garages actually on the walls and slopes, maximising the developable area for the Client.

This approach has meant that the site has been developed with minimal impact on its surroundings due to minimising export and import to site, the final aesthetics are pleasing to the eye and the Client has welcomed a cost effective solution to a challenging situation.

Keywords: earth reinforcement, geogrid reinforcement, geosynthetic, geotextile, mechanical, reinforced slope.

INTRODUCTION

As the populous continues to grow and develop, there is an increasing demand for areas of residential housing. The days of ‘easy greenfield sites’ have past , with the remaining sites being challenging, difficult, brownfield sites.

A residential housing development at Podder Lane in Mapperley, Nottingham is one such site. A historical aerial photograph of the site is shown in Figure 1. It can be seen that the surrounding area has already been developed for residential housing, leaving the site ‘locked in’ in all sides apart from the south eastern boundary which backs onto the historical Gedling Colliery.

The main challenges that the site proposed to the design team were:

- How to redevelop the site with minimal impact to the surrounding residents e.g. minimise import/export from the site?;
- How to deal with the historical legacy of the site which brought impacts such as hydrocarbon contamination and the presence of colliery spoil?;
- How can the various constraints that the development possesses be turned into opportunities in order that the development can proceed on a cost effective basis?.

Figure 1. Aerial photograph of development site

SITE HISTORY AND GEOLOGY

Site History

From the desk study, the map of 1885 showed the site to be open land, with Podder Lane as a track leading to Podder Farm, formerly some 160m to the east of the site. This generally remained the case until 1944 when Gedling Colliery had been established 800m to the south-east of the site. The 1955 map indicated that the site had now been partially raised with spoil heaps in areas by up to 13.6m as a result of the adjacent colliery.

In 1967, historical map contours showed that the site had been levelled and the surrounding area to the north and east had been developed with residential properties by 1991.

Since at least 1973 the site operated as a specialist lorry breakers and scrap yard.

Geology

The site was interpreted to be underlain by solid geology of the Gunthorpe Formation of the Mercia Mudstone Group, with Coal Measures strata present at depth. There were no drift deposits indicated on the geological mapping. The Mercia Mudstone Group typically comprises red brown silty mudstones, which weather to clays, with subordinate grey green interbeds of siltstone, known as skerries. Made Ground was shown to be present on the north-eastern half of the site.

FEASIBILITY STUDY

Area of the Study

One of the areas that the design team focused on was the south eastern boundary with the historical Gelding Colliery. This was a sloping boundary which comprised colliery spoil (up to 7m) overlying Mercia Mudstone. A drainage channel was also coincidental with the boundary.

Scope of the Study

A feasibility study was undertaken in order to ascertain how this boundary could be incorporated into the development. The feasibility study comprised:

- Preliminary ground investigation and establishment of outline geotechnical design parameters;
- The practicality of changing site levels to aid in redevelopment;
- Slope stability analysis both short term and long term;
- Settlement analysis in the short and long term.

Study Findings

An indicative section of the boundary is shown in Figure 2, this shows a schematic of the existing site boundary and a general proposed profile to increase the developable area. The findings of the feasibility study were that 75% of the slope had an inadequate Factor of Safety in its present condition with global Factor's of Safety ranging from 1.00 – 1.25 and all of the slope being inadequate if site levels were to increase to aid in redeveloping the site. The settlement analysis also confirmed that any structures founded on the significant depths of colliery spoil would undergo unacceptable levels of total and differential settlement.

Several remedial solutions were proposed and determined. These comprised:

- Stabilise the existing slope with soil nails and then raise the site levels via a conventional gravity retaining wall – rejected due to overly complex implementation and multiple contractors/trades required;
- Install an embedded retaining wall to stabilise the slope which could also be used to raise levels – rejected to onerous temporary works required and cost of wall to raise levels;
- Excavate the slope and install a 'traditional' gravity retaining wall (e.g. mass concrete) – rejected due to the volume of import/export of material required;
- Excavate the slope and install a reinforced soil retaining wall – accepted on the basis that the import of materials would be minimal and that the colliery spoil could be utilised in the construction of the wall.

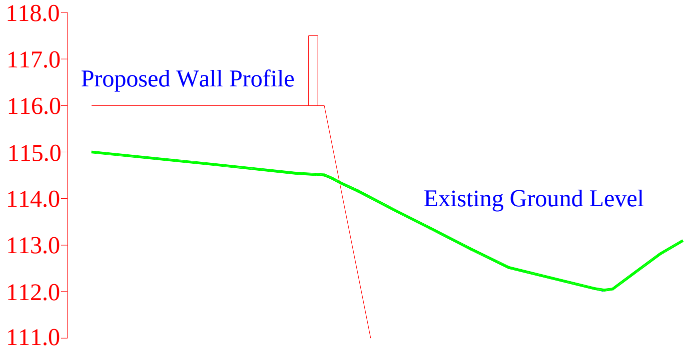

Figure 2. Schematic of existing and proposed ground levels

DETAILED GROUND INVESTIGATION AND DESIGN PARAMETERS

Ground Investigation

Further ground investigation works were undertaken in order to carry out in-situ testing and to gain samples for laboratory testing for geotechnical design parameters to be ascertained for detail design. The further site investigation comprised:

- 8 No. Cable Percussion Boreholes;
- 3 No. Trial Pits;
- 3 No. Windowless Sample Holes.

Geotechnical Testing and Design Parameters

A summary of the geotechnical design parameters are presented in Table 1. A series of particle size distribution tests (Figure 3) were undertaken on the colliery spoil confirming that it could be classified as a 6I or 6J material in accordance with the Manual of Contract Documents for Highway Works (MCDHW, 2006). In order that the earthworks can be monitored on site in a timely fashion, a series of Proctor Compaction Tests and Moisture Condition Value/Moisture Content relationships were also carried out. The results are shown as Figure 4. Other salient engineering parameters (Standard Penetration Test (SPT), Undrained Shear Strength (c_u), Plasticity Index (I_p) and Moisture Content (mc)) are shown on Figure 5.

Table 1. Summary of geotechnical parameters

	Colliery Spoil	**Mercia Mudstone**
Parameter	**Range**	**Range**
Moisture Condition Value	9 - 12	
Optimum Moisture Content*	20 – 23%	
Co-efficient of Volume Compressibility		0.13 m^2/MN
Undrained Shear Strength	15 – 50kPa†	95 kPa – 170 kPa
Standard Penetration Test ‘N’ Value	1 – 13	29 - 60‡
Plasticity Index		7 - 13
Moisture Content	16 - 32	12 - 27
Internal Angle of Friction	30.5^0	
Apparent Cohesion	5 kPa	
Modulus of Elasticity (Drained)		
pH	7.4 – 8.2	
Total Sulphate	290 – 1800mg/kg	
Redox Potential	440 – 550mV	
Resistivity	29 – 37Ωm	
Oxidised Sulphide	<0.01%	
Acid Soluble Chloride	<0.01%	
Organic Matter	0.4 – 4.2%	
Microbial Activity Index	Inactive	

*For earthworks compaction
†Cohesive elements only
‡Values omitted over 60 for clarity

Groundwater Levels

A series of groundwater monitoring points were installed along the south eastern boundary in order to monitor the groundwater flowing from the site to the drainage feature along the site boundary. As expected the groundwater was shown to be perched on top of the Unweathered Mercia Mudstone at depths from 3.8m to 6.5m below proposed ground level, flowing from the North East to the South West.

REINFORCED SOIL SLOPES DESIGN

Introduction

Unlike many civil engineering designs traditionally carried out in the United Kingdom to a permissible stress approach, reinforced soil slopes are designed from a limit state perspective. The design of the reinforced soil slopes were carried out to BS 8006:1995. In general terms it can be said that partial factors are used to increase any negative or disturbing forces and decrease any positive or restoring forces. The limit state is then satisfied when the restoring forces are equal or greater than the disturbing forces.

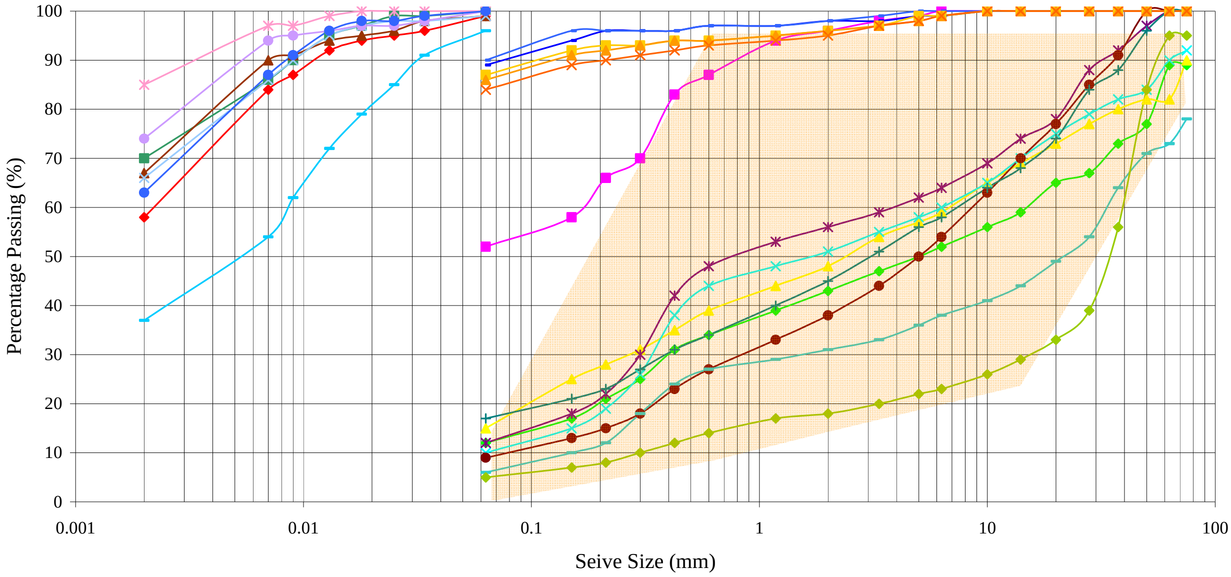

Figure 3. Particle Size Distributions for Colliery Spoil

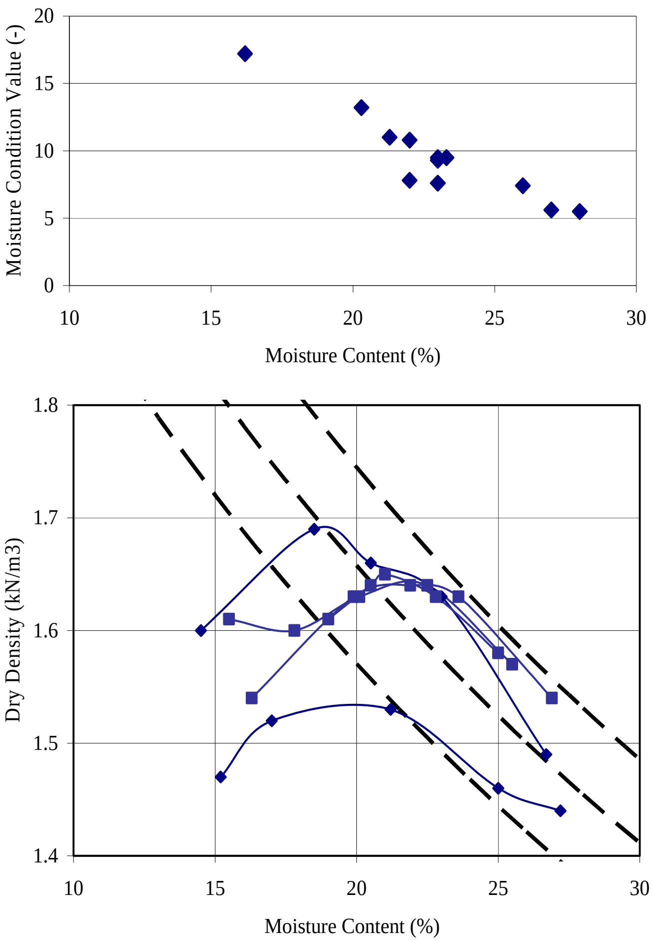

Figure 4. Dry Density and Moisture Condition Value vs Moisture Content for Colliery Spoil

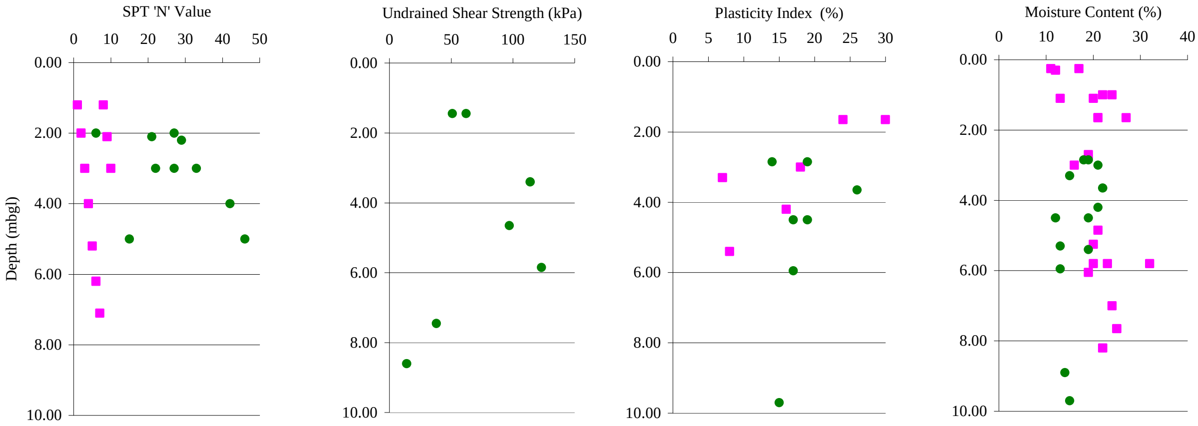

Figure 5. Geotechnical depth related design parameters. Pink-colliery spoil; green-Mercia Mudstone.

There were two types of reinforced soil slope that were designed for the development:

- The first comprised a 'normal' reinforced slope with little or minimal surcharge from gardens and hardstandings etc.;
- The second was slopes that were utilised to support foundations for structures such as houses and garages.

Design Challenges

With regard to the 'normal' reinforced soil slopes, the main design challenge that had to be overcome was drainage for the structures. Standard practice for gravity retaining wall design is to place drainage materials either under or behind the structure (or both) which is then positively drained. The challenge that the site presented was that this practice could not be reasonably adopted due to the groundwater levels. The final design was to incorporate multiple levels of horizontal drainage layers to allow the water to drain through the wall, which would then be picked up by (a) plants in a green face and (b) the drainage feature which was designed to be reinstated upon completion of the construction works.

As well as the drainage aspects, the walls which were supporting the structures presented a different set of challenges. The main challenge was the increased load from the structure to the geosynthetics. Normal loading would be of the order 10kPa – 20kPa, whereas typical residential structures impart bearing pressures of 120kPa – 150kPa. Obviously this is from an Ultimate Limit State perspective. When looking at the Serviceability Limit State perspective, the main criteria that needs to be met is differential settlement as not all of the structure could be economically founded on the reinforced earth slope. To overcome both of these issues, a raft foundation was designed for the structure with a transition zone being created between the reinforced earth wall and the remainder of the site. This transition zone being a benched construction which would gradually reduce the potential for differential settlement.

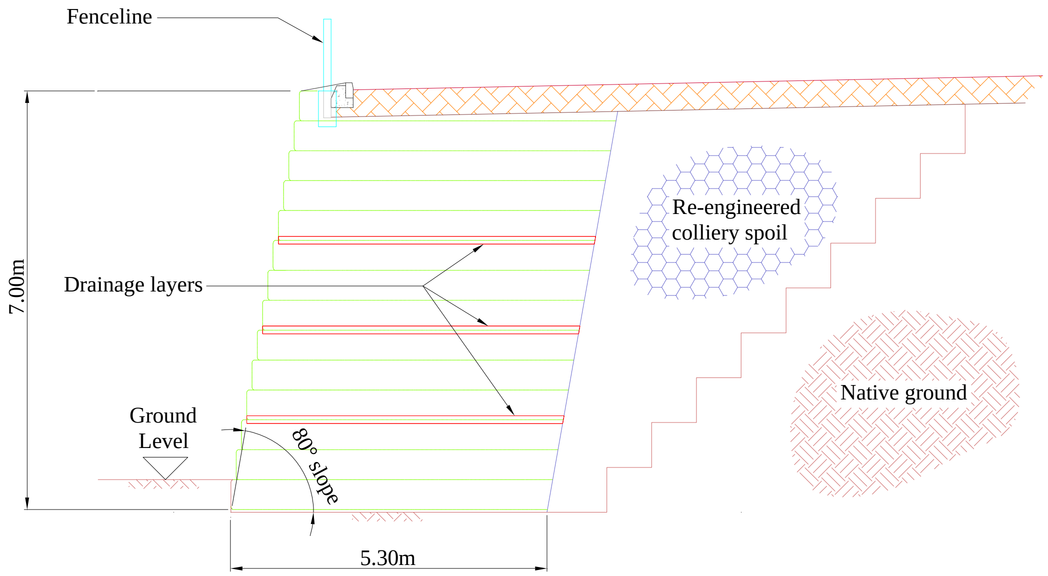

Figure 6. Typical example of reinforced earth slope

One remaining factor was taking into account to limit the potential movements for the walls that were supporting the structures – ongoing movement of the geosynthetics following construction of the wall. Normally, walls would be designed to limit post construction movement to 1% strain. Through the design process, one risk that was identified was given the granular nature of the colliery spoil, there would be very little post construction settlement associated with this material. If the geosynthetics strained too much then this may also lead to problems of differential settlement.

In order to overcome this, the walls that were supporting structures were designed as if they were bridge abutments and the post construction strain was limited to 0.5%. Typical examples of the structures are shown in Figures 6 and 7.

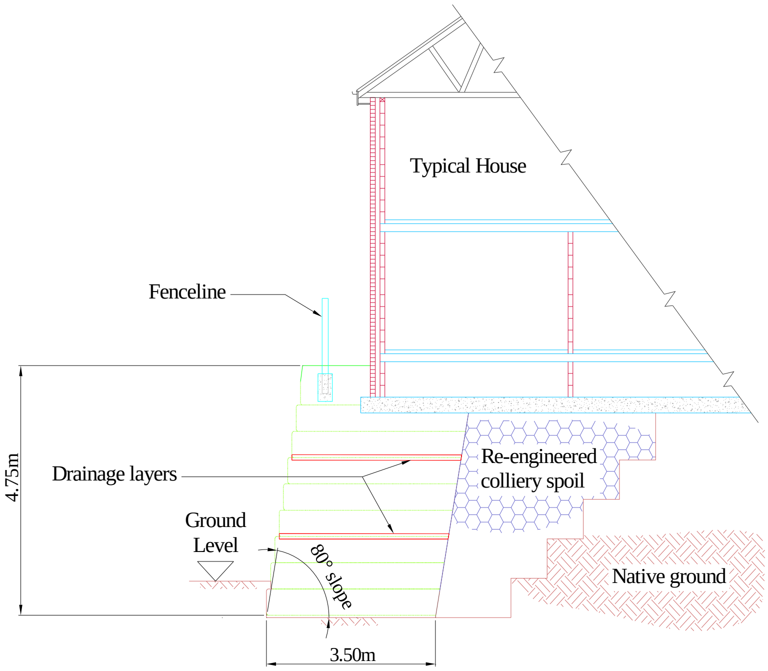

Figure 7. Example of a Reinforced Earth Slope supporting a structure

MECHANICALLY STABILISED EARTH WALL DESIGN

Introduction

Part of the slope formed a turning head which would be adopted by the Local Authority post construction. The design of this had to be undertaken both in accordance with BS8006:1995 and the Design Manual for Roads and Bridges (DMRB, 2003). One interesting part of the DMRB is that it does not allow wraparound facings, one of the obvious risks being vandalism prior to the face 'greening up' (Hong Kong Geoguide 6, 2002). To this end, it was proposed that for this section a Mechanically Stabilised Earth Wall (MSEW) could be designed which would have a gabion basket finish. The gabion facing could also be designed to have a green face to fit in with the overall aesthetics of the development and area.

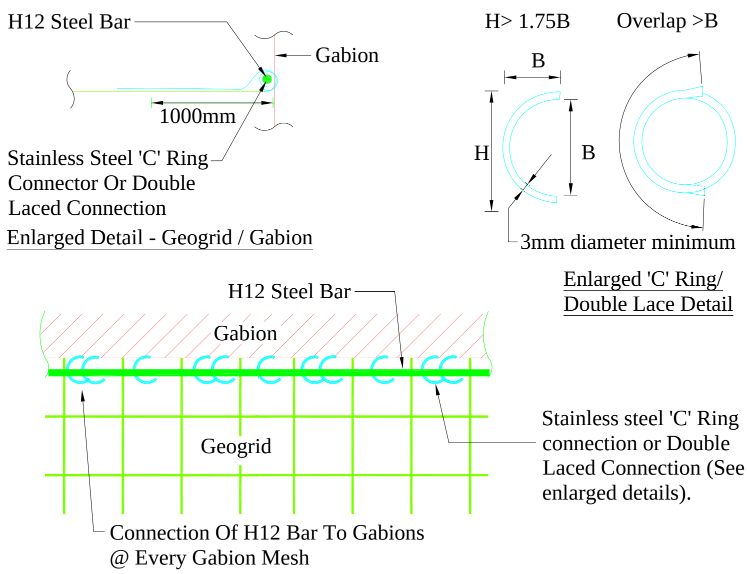

Figure 8. Example of a geogrid – gabion connection

Design Challenges

From an overall perspective it may be argued that the design of a mechanically stabilised earth wall is just the same as any other gravity wall and certainly from an external stability perspective this is indeed the case. Sometimes, though, the devil is in the detail and one of the most overlooked things is the connection detailing between, in this case, the gabions and the geosynthetics. This also leads to some negative images of MSEW's in the UK as the perceptions is that these connections are difficult to design and challenging to construct. This is, however, not the case.

The perceived problem is one of localised stress. The design codes require that the connections are capable of transferring 75% and 100% of the maximum tensile stress in the reinforcement at the top and the bottom of the wall respectively. From a localised perspective, an individual gabion wire or geosynthetic strand would not be able to withstand this stress. One solution would be to embed the geosynthetics between the gabion baskets, however, in some instances the purely frictional resistance would not be enough, even though in some countries this is standard practice FHWA (2001).

This issue can easily be overcome by wrapping the geosynthetics around a high tensile steel bar and then connecting the bar to the gabion baskets. In this way there was a much more uniform transference of stress between the geosynthetic and the gabion baskets. The detail is shown in Figure 8 with a typical section of the wall in Figure 9.

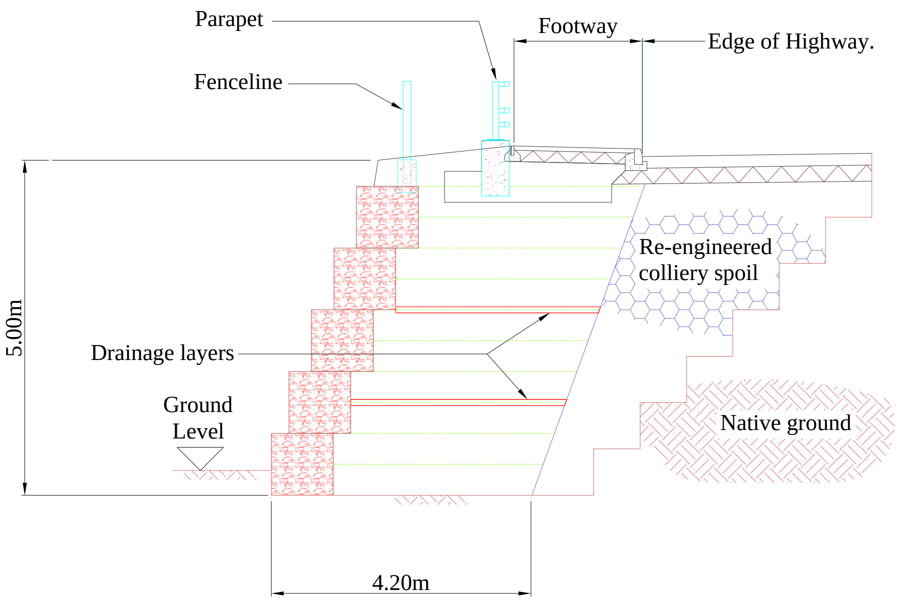

Figure 9. Mechanically stabilised earth wall

ADDITIONAL BENEFITS TO THE DEVELOPMENT

There were also a number of other benefits to the development apart from the ones which have been previously discussed above. For brevity they are listed below:

- During the construction of any development, apart from the main 'earthworks' volume calculations, there are also additional arisings from excavations such as those required for services. In this development, these were also able to be incorporated into the geosynthetic wall and slope construction;
- As the previous use of the site was a scrap yard, there was some hydrocarbon contamination in the soils. These soils were already proven not to pose a risk to the groundwater and as geosynthetics are generally resilient to hydrocarbons, it was possible to include them in the wall and slope construction also;
- All developments should be sympathetic to their surroundings. This may have been difficult with other walls which presented different facing profiles, however the geosynthetic walls and slopes were all able to be designed with green facings in order that they blended more naturally into the environment.

SUMMARY AND CONCLUSIONS

It has been shown that through the careful planning, consideration and a feasibility study of various methods, sites which at first appear to be challenging, costly to develop and may have a significant affect on the immediate environment can be developed without any of the aforementioned coming to fruition. The benefits of feasibility studies and outline designs are well known and have been documented for many years (Oliphant, 1997) but are often neglected under commercial pressures. Ironically, it is the implementation of these that may lead to easing the same commercial pressures.

The use of geosynthetics can play an important role in achieving the end goal of cost effective and minimal environmental impact development on these challenging sites.

The benefits of using geosynthetics in the redevelopment at Podder Lane has allowed:

- Materials that may traditionally be deemed as being 'unsuitable' for incorporation into engineering works to be utilised to a beneficial affect;
- A number of geosynthetic designs to be incorporated into one scheme, with seamless integration between them, to overcome various challenges;
- Sympathetic aesthetic design to the surrounding environment and allowed the new development to fit in with the historical surroundings;
- The use of lateral design approaches with regard to detailing e.g. drainage and connections which has led to savings with regard to cost and time for construction;
- A wide range of loadings conditions to be designed for utilising similar overall construction techniques;
- Different design criteria being able to be adopted for the same materials to enable different limit states to be satisfied;
- Flexibility with regard to facing materials to be adopted.

Overall, not only has the scheme benefited from the use of geosynthetics, but also the surrounding environment, but with regard to the actual construction and the ongoing beneficial use of the development.

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