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USING GEOSYNTHETICS TO MEET THE CHALLENGE OF IMPROVING MATERIAL RESOURCE EFFICIENCY

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Abstract: Sustainability takes many guises. A start towards achieving sustainability in construction is to manage the resources that are available in such a way as to limit the long-term adverse effects of their use. Efficient use of the limited resources available is a logical step towards this. Earthworks typically require very large quantities of imported materials, while similarly large quantities of natural material are exported to landfill. On many levels this can be branded inefficient.

Fundamentally this means that the demand for primary aggregates must be reduced. The corollary is that lower performance materials must be used in their place.

It is known that lower performance materials, including site won and recycled, can more readily be used on site if geosynthetics are incorporated into the design. It is further expected that the range of applications for geosynthetics will grow, increasing the potential for use of such low performance materials. It is proposed that the benefits of using geosynthetics outweigh the environmental consequences of their manufacture and distribution.

A measure of the carbon footprint of materials and processes is becoming more common in the construction industry as a tool for comparison of whole-life environmental impact of alternative schemes. It is recognised that carbon footprints can partly assess the ability of geosynthetics to have a beneficial effect on the efficiency of construction in the UK. Coffey Geotechnics together with EnviroCentre are conducting a study for the Waste and Resources Action Programme (WRAP) into the 'cradle to site' carbon footprints of alternative construction techniques for common earthworks and the sourcing and production of materials. The benefits of geosynthetics in terms of maintenance regimes and the durability of earthworks are also investigated.

This paper introduces the study and highlights preliminary findings on the contribution of geosynthetics to the sustainability of earthworks.

Keywords: design, durability, efficiency, fills, geosynthetic, soil reinforcement.

INTRODUCTION

This paper provides an introduction to research being carried out to assess the environmental benefits available by using geosynthetics in construction. The focus of the study is the potential for geosynthetics to increase material resource efficiency by enabling the reuse of a greater proportion of site-won and lower-performance materials, hence reducing reliance on primary aggregates.

It is becoming increasingly important for businesses to be aware of the contribution they are making to global CO_2 emissions. Traditionally, this pressure has been applied by environmental awareness groups and political bodies. However, there is currently a sizeable media ‘buzz’ surrounding the topic that is leading to a client demand for sustainable solutions and places commercial pressures on businesses.

The construction sector is a major consumer of fuel and primary materials. In addition the sector is a major contributor to the quantity of material sent to landfill sites. Sustainability bodies such as the Waste and Resources Action Programme (WRAP) are therefore campaigning for the construction sector to increase their material resource efficiency. The construction industry has the potential to realise substantial cost and carbon savings through using geosystems.

The study uses the term ‘geosystem’ which is defined here as a composite working system in the ground which includes engineering input, soil and geo-components. Geo-component is a generic term referring to the particular engineering product in the geosystem, often but not always geosynthetic based.

A geosystem gives the designer the ability to use site-won material that may otherwise be geotechnically unsuitable. The benefits of this are threefold:

- Eliminating the need for imported primary aggregate;
- Reducing the volume of material disposed to landfill; and
- Reducing transportation arising from an optimised on site cut/fill material balance.

Geosynthetics can facilitate the use of recycled materials and additionally have the potential to be manufactured from recycled material themselves. The use of site-won fill with geogrids is becoming accepted practice, with the use of crushed construction and demolition 'waste' increasing. Limited research has been carried out to assess the long-term integrity of geogrids manufactured from recycled plastics and the potential extent of the dual recycling benefits is yet to be realised. This is discussed further in the consultation section of this paper.

The study intends to show the industry – of clients, regulators, designers and contractors – the additional value that can be gained through the use of geosynthetics. The general advantages of geosystems are investigated rather than comparing alternative/competitive geosynthetic products. Two key indicators will be assessed: monetary cost and carbon footprint.

METHODOLOGY

The initial part of the study was to collate information on a wide range of geosystem applications and components. The relative merits of a selection of these applications and components were then assessed against conventional construction techniques for a number of specific scenarios. The outline project methodology is presented below:

- Desk-based review of available literature;
- Collation of current and emerging applications of geosystems;
- Consultation with geosynthetic manufacturers and suppliers;
- Development of scenarios to enable comparative carbon footprint and cost benefit analyses; and
- Drawing of conclusions and recommendations for further developments.

The desk-based review aimed to establish the current use of geosystems in UK construction. A large number of applications were identified and the purpose of the geosynthetic component in each was assessed.

A key part of the study was consultation with geosynthetic suppliers and manufacturers. A questionnaire was compiled and sent to 18 geosynthetic manufacturers and suppliers and each was invited to have further involvement with the carbon footprint assessment. A positive response was received from seven organisations, with a number of others declining to respond on the grounds of commercial confidence.

Six scenarios were produced to enable comparison between geosystem and non-geosystem based construction methods. The scenarios were chosen to reflect common applications and were based on case histories using geosystems in place of conventional, often 'hard', engineering solutions. Preliminary design was undertaken for both solutions in each case. The six scenarios are listed below:

- Temporary access over soft ground: Reduction in aggregate thickness by incorporation of geogrid reinforcement;
- Reduction in road pavement thickness: Reduction in asphalt thickness by incorporation of geocomposite reinforcement;
- Utilising low-performance materials: Use of lower quality material by incorporation of geosynthetic reinforcement;
- Retaining wall: Use of reinforced soil wall in place of reinforced concrete wall;
- Drainage during construction: Use of drainage geocomposite in place of imported granular drainage layer; and
- Slope stabilisation with limited access: Soil nails.

Each scenario considers a linear feature, e.g. embankment or road pavement, of unit length 100m to allow direct comparison of the material demand and resource efficiency. The relative CO_2 impacts of the geosystem application and the conventional construction technique will be assessed on the basis of the weight of the geo-component incorporated within the geosystem and that of the displaced construction materials. Similarly, the cost-benefit of the different construction techniques will be quantified based on unit rates for construction materials, including plant and labour.

Figure 1 shows the scenario for 'temporary access over soft ground' where the use of a biaxial geogrid reduces the volume of aggregate needed by approximately one third.

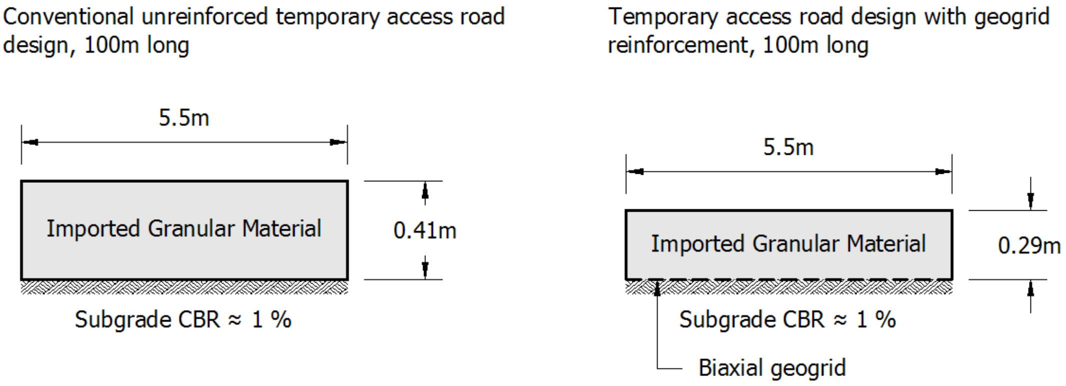

Figure 1. Scenario for temporary access road

In order to facilitate comparison, transportation distances were assumed to be the same for each scenario. It was assumed that in each case there is a local source of aggregate, and manufactured components including geosynthetics will have a larger distance to travel to site. Transportation distances are assumed to be relatively short to ensure that the final calculated carbon footprint will not be skewed unduly by haul distances which are essentially a project specific variable. The specific methodologies for both the carbon footprint and cost-benefit analysis are discussed further in their respective sections below.

The six scenarios illustrate the variety of applications across the geosystem market, and a number of other geosystem solutions may be appropriate for each. There may be subtle differences between the carbon footprint and cost-benefit of different geosystems. However, the purpose of the study is to enable appropriate comparison between geosystems and conventional systems in general as opposed to producing accurate total costs and total carbon footprint. Any differences between geosystems are considered to be overshadowed by the benefits of a geosystem in place of a conventional system.

CONSULTATION

Manufacturers and suppliers were consulted by questionnaire, responses to which were followed up by telephone and face to face interviews. The aims of the questionnaire were to:

- Establish key geosynthetic products on the market;
- Identify recent and potential future developments in geosynthetic product, manufacture and application;
- Obtain an overview of manufacturing processes for the purpose of carbon footprint assessments; and
- Indentify perceived barriers to adoption of geosynthetics and the use of recycled materials.

Seven positive responses to the questionnaire were received. Manufacturers provided information about their current products and reported increases in material efficiencies, both in terms of achieving the same product performance using less polymer and greater factory process efficiencies. One manufacturer commented that they had recently halved transportation costs by reducing the weight of their products.

All responding parties provided opinion on the barriers to increased use of geosystems and the potential for greater incorporation of recycled content. The main barriers identified fall into the following categories:

- Recycled content
- Education
- Commercial Pressures
- Standards and Guidance

These barriers and potential ways of overcoming them are discussed below.

Recycled content

Geosystems comprise two main physical elements: soil and geo-component. Both elements can be predominantly primary material or may include some recycled content.

Respondents to the consultation cited Designers and Regulators as the groups that most often present a barrier to increasing the recycled content of geosystems. Clients, Main Contractors, Sub-Contractors, national and international standards organisations such as CEN, and some geo-component manufacturers were also perceived to provide barriers.

The potential to use recycled material in both the soils and geo-components that make up the geosystems is discussed below.

Soils

For the purposes of this paper the term ‘soils’ is taken to include soil, rock and aggregate. Site-won or other local soils may be reused on site within a geosystem. Reuse of site-won material is attractive in terms of sustainability as disposal of excavated material is reduced and high value materials need not be imported. Recycled aggregate may also be derived from construction waste, primarily concrete and brick. Recycled aggregates are commonly used in highway construction and are specifically permitted in the Specification for Highway Works with reference made to compliance with the WRAP quality protocol. Recycled aggregates are generally used in the lower value parts of road construction such as capping and sub base layers; however, their use is increasing in the asphalt overlay. Recycled aggregates are also used in unbound fill applications such as backfill (with or without geosynthetic reinforcement) or drainage layers.

Manufacturers report that they are continuing to develop products to be compatible with recycled soils and aggregates, although many specifications for permanent works still prohibit the use of recycled aggregates due to concerns over variability within the material.

Geo-components

Geo-components may be manufactured using recycled materials; they may also be reused on subsequent projects. Manufacturers report that most of their products could be either reused or recycled. The potential to reuse geo-components will depend on the nature of the first use and the methods of construction and demolition of that project. Geogrids used for some temporary works may be technically suitable for reuse, but the grids may be damaged during dismantling of the temporary works and so be unfit for reuse. Imported polymer may be replaced by material from recycled plastics. Some manufacturers state that they reuse their own ‘waste’ e.g. selvedge off-cuts and trimmings as part of the manufacturing process.

Manufacturers report a perception on the part of clients and/or specifiers that the design life and durability of geosynthetics incorporating recycled materials are lower than for those made from virgin materials because recycled fibres and resins are of poor quality that cannot be controlled. Some manufacturers felt that this view is perpetuated by competitor manufacturers who market non-recycled products. Most manufacturers said that standard specifications often prohibit the use of recycled materials.

The main barriers to adoption of recycled materials were identified by respondents as a lack of understanding of polymer technology and lack of clarity over design lives for recycled materials. Most manufacturers quote 120 year design lives for specific geogrid products, but some note that the maximum design life attributed by CE Marking is 'greater than 25 years' and that testing of recycled products to demonstrate a higher design life is prohibitively expensive.

Manufacturers generally agree that the barriers to adoption of recycled materials could be overcome by further research into the durability of such materials so that designers could be given more assurances of the material quality. Respondents recognise that WRAP is continuing work to promote the use of recycled plastics and it is proposed that the recommendations of this report are fed into that work.

Education

Manufacturers cite lack of technical understanding as the main barrier to adoption of geosystems in general. A lack of knowledge of the potential applications of geosystems and an unease of working with 'new' materials are identified amongst designers. Respondents note that recent graduates are generally more willing to specify geosystem solutions than established engineers. Most manufacturers offer design services as well as supply of materials and recommend that a system design is procured, rather than just a product, to ensure that the most appropriate geosystem is used. Most manufacturers recognise the need to maintain a strong technical presence to assist designers throughout the design process.

Commercial Pressures

Manufacturers identify commercial pressures as a key influencing factor in the adoption of geosystems. Commercial pressures are identified as a barrier on one hand, as designers have a duty to keep costs down for their clients and can be unwilling to take on perceived liabilities and risks associated with new technologies, in addition there can be pressures on a contractor to buy to a budget. On the other hand, commercial pressures are identified as a driver for contractors who often have a larger influence than designers on procurement decisions when cost or time savings can be achieved by using a geosystem. Recent waste minimisation legislation (Site Waste Management Plan Regulations 2008) may also provide an additional commercial driver for the reuse of site-won materials as part of geosystems as an alternative to exporting waste and importing other materials.

Standards and Guidance

Manufacturers identify that regulator guidance (e.g. as issued by the Highways Agency) and general specifications typically have a bias towards more established technologies and can make it difficult for emerging techniques to be approved. Respondents further note that designers tend to be reluctant to use geosynthetics in applications other than those that are already accepted in national codes and standards. It is recognised that designers often do not have the budget or programme to pursue a novel approach, even if it could eventually be approved by special provision of the regulating authority. Manufacturers said that they would welcome closer cooperation with regulating authorities to work towards the inclusion of new materials and geosystem techniques in standard guidance, for example CIRIA.

CARBON FOOTPRINT ANALYSIS

Businesses are increasingly looking to demonstrate the sustainability credentials of their products partly in response to the corporate social responsibility agenda and of course in order to gain a competitive advantage. Geosystems have great potential to reduce the carbon footprint of construction through enabling reuse of site-won materials and a reduction in primary aggregate volumes.

The material components of both geosystems and conventional structures have embodied energy due to the energy used in their production. Further energy is used in transportation and construction activities on site. This energy can be converted into an equivalent mass of carbon dioxide released to the atmosphere. The carbon footprint of conventional and geosystem solutions can be compared to assess the savings achieved by replacing volumes of primary aggregate (for example) with geosynthetics and lower performance materials.

The purpose of the assessment is to quantify the differences in carbon footprint between typical conventional and geosystem solutions. Subtle differences between competitive geosynthetics are considered to be overshadowed by these. The embodied energy for a generic geosynthetic suitable for each scenario will therefore be calculated.

It is essential in carbon footprint assessments that the boundary conditions of the calculation are clearly defined. The carbon footprint calculations were undertaken in accordance with published guidance (Carbon Trust, 2007; EA, 2007; WRAP, 2005; and WRAP, 2006).

COST BENEFIT ANALYSIS

A cost benefit analysis has been carried out on each of the scenarios to complement the carbon footprint assessment and to provide a context for the results. Material and construction costs were calculated for the conventional and geosystems in each case, and the percentage cost difference calculated. The costs are for construction of the respective structure only, and associated costs common to both systems will be omitted from the calculation. Where indirect issues, such as the accessibility of the site, are important considerations during the selection of the construction approach these are commented on qualitatively within the cost-benefit discussion for each scenario. The costs are not intended to be definitive on the total cost of each scenario; rather they are aimed at showing the savings available for two comparable quantities. There will be further costs associated with each scenario but they are expected to be equal in value for both cases; for example, processes such as surface preparation or establishment on site would produce equivalent costs.

DISCUSSION OF PRELIMINARY FINDINGS

Preliminary results shown that, typically, opting to utilise a geosystem will provide cost savings, mainly due to the material resource efficiencies created. The cases assessed are fairly standard situations where a geosystem should be considered in the feasibility study. It is acknowledged that in some situations geosystems may not be appropriate. The largest cost saving calculated is for the reinforced embankment. The use of geogrid reinforcement and geocomposite facing allows the utilisation of poor site-won materials therefore creating material resource efficiencies. It is these efficiencies that allowed the large cost savings through a reduction in the import of construction materials. The savings produced in other scenarios were more subtle but were still evident.

It is useful to consider one of the examples in greater detail. The drainage scenario is based upon an actual case history which involved the direct replacement of primary aggregates through using a geocomposite drainage layer in place of a 300mm thickness of stone with a geotextile separator, as shown in Figure 2. The project required construction of an 11m high noise attenuation embankment just within the site footprint, with the embankment to utilise site-won soils. The site soils were predominantly cohesive for which the maximum safe slope was assessed at 1:2.5 under drained and undrained conditions. At one location, for a length of about 300m, construction of this embankment at slopes of 1:2.5 would have meant that the embankment reached to the boundary and in places went slightly beyond the boundary. Just inside the boundary there was a requirement for a 5m access track for maintenance and security vehicles.

A range of design options was considered, including:

- Purchase of additional land beyond the existing boundary to allow construction of an unreinforced 1:2.5 slope and the access track;
- Geosynthetic reinforcement of the boundary fence side of the embankment to allow steeper slopes;
- Creation of a toe berm of about 3m vertical height with a 70° geosynthetic reinforced wall and construction of the access track on the horizontal surface formed at the berm crest; and
- Incorporation of a drainage layer at the base of the boundary fence side of the embankment to allow control and dissipation of pore pressures within the embankment, hence safely allowing steeper slopes under long-term, drained conditions.

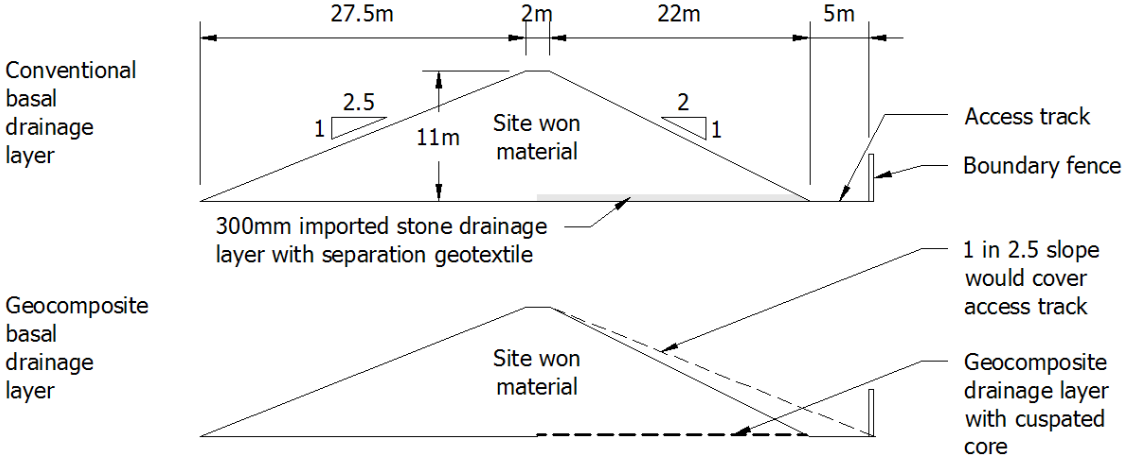

Figure 2. Basal drainage scenario

The first option of additional land purchase was not practical. The second and third options of geosynthetic reinforcement to create a steeper slope or a toe berm were both practical and achievable, but were considered disproportionately costly for the perceived benefit. Attention then focussed on controlling the pore pressures within the embankment soils by means of a drainage layer at the base.

The 'default' approach to creating a drainage blanket is to build a layer of free draining granular material, which would have required the import of virgin aggregate to site. The alternative approach is to use a drainage geocomposite. The costs were assessed for each sub-task within the two approaches using standard price references. The cost associated with importing the required 300mm thickness of granular fill and placing a separation geotextile over this was approximately equal to the cost of the geocomposite drainage material.

The additional cost of excavating and placing the volume of site-won fill material above the geocomposite pushed the cost for the geosystem above that of the conventional construction method. The wider benefits of the geosystem were then reviewed to see what other savings were achievable. For the conventional approach a temporary haul road would have to be provided to allow the large volume of stone required to construct the drain to be transported to the site. The cost associated with providing a 100m length of haul road equated to a net saving through using the geosystem and in reality the temporary road would have been much longer. This scenario highlights the range of benefits available through the utilisation of geosystems. Geosynthetics are usually more lightweight than conventional primary materials. As a result, further cost and carbon savings, as well as programming advantages, can be achieved by reduced trafficking.

Preliminary results indicate that significant carbon savings are obtainable by using geosystems instead of conventional engineering solutions. The key contributors to the carbon savings are:

- Reduced import of material (haulage);
- Reduced use of primary aggregates (embodied energy);
- Reduced disposal of site-won material (haulage); and
- Faster, lightweight construction (reduced construction effort).

CONCLUSIONS

The study into the potential for geosynthetics to increase material resource efficiency, by enabling the reuse of a greater proportion of site-won and lower-performance materials and reducing reliance on primary aggregates, is ongoing. Preliminary results indicate that utilising geosynthetics in construction not only provides cost savings, but also reduces the carbon footprint of the construction process. Crucially, the carbon footprint of the ‘geocomponent’ is often significant but generally appears to be more than offset by the carbon savings provided. This comparison is expected to be a key output from the research. During the consultation manufacturers stated that research is tending towards greater efficiencies in production through more efficient processes and lighter weight materials. This should enhance the savings demonstrated by the research thus far.

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