Material change for a better environment

Geosystems Report, February 2010

Sustainable geosystems in civil engineering applications

Geosystems provide alternatives to some standard materials and designs used by civil engineers. This guidance document explains what geosystems are, and how they can be used to provide sustainable and cost effective solutions.

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WRAP's vision is a world without waste, where resources are used sustainably.
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CAPITA SYMONDS

Front cover photography: A30 Bodmin Bypass, Holywell Embankment; Formed of a geogrid wraparound face Geosystem using site won fills
Photo courtesy of Alfred McAlpine / Huesker Ltd.

Executive summary

This guide is designed to help everyone involved in developing construction solutions (clients, designers, contractors and regulators) to understand when, where and how ground engineering Geosystems can provide cost-effective and programme-efficient solutions which simultaneously cut both materials wastage and the carbon footprint of construction.

The extent of the opportunity

Around 20 million tonnes of construction, demolition and excavation are sent to landfill annually in England[1].

WRAP (Waste & Resources Action Programme) is actively involved in the Waste Strategy to halve the amount of waste sent to landfill by 2012.

Increased in-situ treatment of soils and increased recovery of excavation waste (both achievable through the wider use of Geosystems) can assist in meeting this target.

Geosystems can contribute solutions to ground engineering challenges that are significantly more environmentally efficient and cost effective than traditional approaches, particularly those reliant on concrete. The construction of retaining walls provides clear illustrations of this.

This report defines and describes Geosystems, and sets out how to use them. Illustrative case studies are provided, to show and quantify their potential environmental, financial and programme benefits.

[1] *Source: Strategy for Sustainable Construction June 2008 - BERR*

Contents

Figures

List of Acronyms

- BBA: British Board of Agrément
- BRE: Building Research Establishment
- BRP: Basal Reinforced Platform (aka LTP)
- BS: British Standards
- CIRIA: Construction Industry Research and Information Association
- CO2: Carbon Dioxide
- ECO2: Embodied Carbon Dioxide
- EE: Embodied Energy
- ERA: Earth Research Associates
- ENISO: European Norm International Standards Organization
- GEC: Geotextile Encased Columns
- HA: Highways Agency
- HDPE: High Density Polyethylene
- ICE: Inventory of Carbon and Energy
- IGS: International Geosynthetics Society
- LDPE: Low Density Polyethylene
- LTP: Load Transfer Platform (aka BRP)
- PA: Polyamide
- PET: Polyethylene Terephthalate
- PP: Polypropylene
- PVA: Polymerized Vinyl Alcohol
- WRAP: Waste & Resources Action Programme

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Geosystems report

1.0 Scope of Guidance Document

This document provides guidance on the use and application of Geosystems in civil engineering. It defines what they are, their component parts and how they work, and provides illustrations to show how they can be used as viable alternatives to the materials and techniques more commonly used in ground engineering.

Case studies show how using Geosystems has the potential to yield significant reductions in carbon emissions compared to conventional solutions, as well as substantial savings in cost, time and material wastage.

1.1 Background

The preparation of this guidance document was commissioned in response to the findings of WRAP report AGG105-006, which evaluated the potential for the wider use of Geosystems (defined as the composite working system in the ground. This includes engineering input[2], soil and an engineered geo-component) to improve material resource efficiency in civil engineering, and to reduce carbon emissions attributed to ground engineering aspects of construction projects.

This initial WRAP report concluded that such gains were indeed attainable, particularly where Geosystem-based solutions displace traditional designs based on concrete or steel, both of which have high levels of embodied carbon.

Relative sustainability for a particular ground engineering project (or element of a project) is assessed by comparing the amount of 'embodied carbon' in the Geosystem solution as a whole, compared to the embodied carbon in the alternative design.

The concept of embodied carbon (or carbon dioxide) provides a measure of the cumulative energy (and hence carbon emissions) required to produce, deliver and use the product concerned. For example the carbon embodied in concrete comes from the extraction, processing and transportation of cement and aggregate constituents.

The embodied carbon in a concrete structure encompasses all these components as well as the finished product where it will be cast. Similarly the embodied carbon in steel reflects the mining of iron ore, its subsequent transportation and manufacture into steel, plus further transportation and processing before the final products are delivered to site. (It should be noted that steel production can contain a large recycled component thus reducing the associated embedded carbon content).

Associated construction activities must also be considered in evaluating the embodied carbon, to ensure that a fully balanced assessment is made which takes account of the directly applicable plant and labour requirements.

These two traditional civil engineering materials, concrete and steel in their structural forms, contribute greatly to the carbon footprint of any construction project. Smaller contributions are made by dredged or quarried primary aggregates. The avoidance or minimisation of the use of these materials through an engineered Geosystem, which incorporates one or more geo-components, can help to reduce the inherent embodied carbon of these same projects.

This reduction is often further enhanced by the Geosystem allowing utilisation of lower specification site-won or locally available soils not normally suitable for ground engineering. This re-use of site won materials additionally enables the reduction in waste being taken to landfill from construction sites.

This simple process can reduce (or even eliminate) the use of structural steel, concrete and primary aggregates via substitution of a traditional design with a suitable Geosystem alternative.

[2] *Engineering input in this context is primarily design and technical expertise*

Figure 1 Gabion retaining wall [11]

Figure 2 Geogrid reinforcement [19]

2.0 Introduction to Geosystems

2.1 Definitions

In the context of construction projects interfacing with the ground, the term 'Geosystem' refers to the composite working system in the ground. This includes engineering input , soil and an engineered geo-component.

'Geo-component' is a generic term referring to an engineered product, often but not always geosynthetic based, used in a Geosystem.

Figure 3 Segmental block retaining wall [11]

Figure 4 Timber crib retaining wall [15]

These fundamental definitions have been used to establish boundaries for the scope of this report, and to enable a clear determination to be made as to which individual applications can be considered as true Geosystems.

2.2 History

Whilst the term 'Geosystem' may be unfamiliar to many readers of this guidance document, the concept is very well established. Indeed examples can be found dating back thousands of years, such as the construction of the Zigurat in ancient Egypt, the Great Wall of China and numerous Roman applications.

The fundamental principle of incorporating a geo-component within a soil has been rediscovered in recent decades, and further developed by the introduction of new materials, improved technologies and more efficient construction techniques.

In more recent times, gabions (rock filled baskets constructed of steel wire mesh), can perhaps be regarded as being the grandfather of the modern Geosystem, with their particular lineage dating back some 130 years. Over the last four decades, however, polymeric products have come to the forefront as a consequence of the expansion of the petrochemical industry producing polymers as a bi-product of the refining process.

Figure 5 High strength uniaxial geogrid [9]

Figure 6 Gabion retaining wall [11]

These polymers were initially used by the textile industry in the 1950s as 'synthetic' fibres in place of the more traditional yarns of cotton and flax. These new fibres began to be used for applications where greater strength was required and they became known in the industry as 'technical textiles'. They were used in industrial and agricultural applications before finding their way into the civil construction markets in the 1970s and early 1980s, when simple geotextiles began to replace graded sand filters.

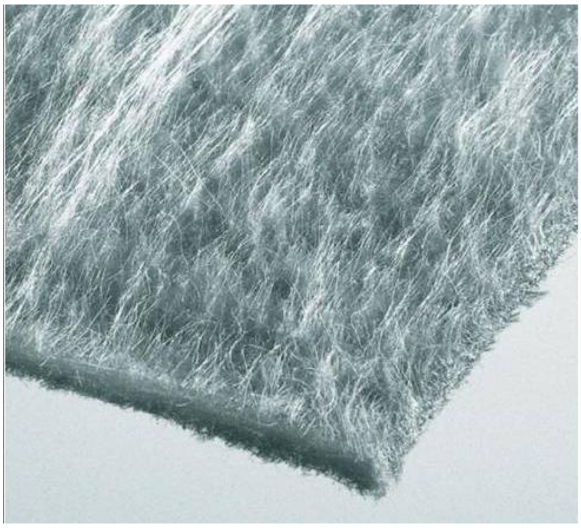


Figure 7 Needle punched non-woven geotextile [18]

At the same time as polymers were winning wider acceptance in the construction industry, other applications were being investigated and trialled. A notable development from the 1970s was the use of steel elements to reinforce granular fills and soil. This simple yet versatile technique gained greater acceptance in the UK throughout the late 1970s and early 1980s, at the same time as both polymeric and steel reinforcement based Geosystems began to be considered for retaining wall and steepened slope applications.

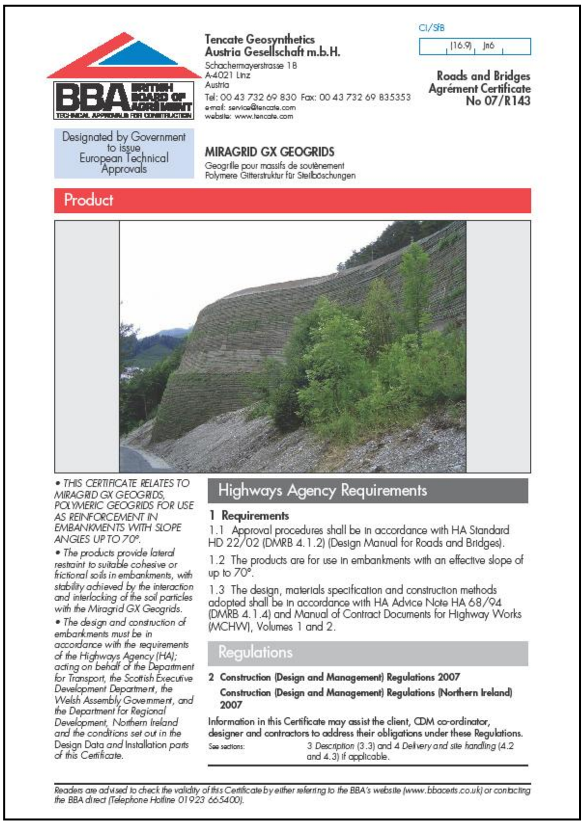
Figure 8 Steel strip reinforced wall system [17]

During the 1980s the growing use of Geosystems across a wide range of UK construction sectors highlighted the need for some standard guidance on their design and specification.

Guidance notes and Codes of Practice appeared in the mid-1990s, including a number of seminal publications such as BS 8002 *Code of Practice for Earth Retaining Structures* and HA 68/94 *Design Methods for the Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques*, both published in 1994. The following year BS 8006 *Code of Practice for Reinforced Soils and Other Fills* was published, and in 1996 CIRIA Special Publication SP123 *Soil Reinforcement with Geosynthetics* was released.

These documents still form the main reference base for the design of Geosystems both within the UK and internationally. Geosystems are now widely used and accepted within the UK civil engineering sector and provide numerous examples of CO2 and cost savings.

In addition to these examples of design guidance documentation, individual geo-component manufacturers have chosen to obtain independent accreditation of their products from organisations such as British Board of Agrément (BBA), Building Research Establishment (BRE), and Earth Research Associates (ERA), to name but a few.



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Roads and Bridges
Agrément Certificate
No 07/R143

Designated by Government to issue European Technical Approvals

MIRAGRID GX GEOGRIDS
Geogrille pour massifs de soutènement
Polymere Gitterstruktur für Steilböschungen

Product

• THIS CERTIFICATE RELATES TO MIRAGRID GX GEOGRIDS, POLYMERIC GEOGRIDS FOR USE AS REINFORCEMENT IN EMBANKMENTS WITH SLOPE ANGLES UP TO 70°.
• The products provide lateral restraint to suitable cohesive or frictional soils in embankments, with stability achieved by the interaction and interlocking of the soil particles with the Miragrid GX Geogrids.
• The design and construction of embankments must be in accordance with the requirements of the Highways Agency (HA); acting on behalf of the Department for Transport, the Scottish Executive Development Department, the Welsh Assembly Government, and the Department for Regional Development, Northern Ireland and the conditions set out in the Design Data and Installation parts of this Certificate.

Highways Agency Requirements

1 Requirements
1.1 Approval procedures shall be in accordance with HA Standard HD 22/02 (DMRB 4.1.2) (Design Manual for Roads and Bridges).
1.2 The products are for use in embankments with an effective slope of up to 70°.
1.3 The design, materials specification and construction methods adopted shall be in accordance with HA Advice Note HA 68/94 (DMRB 4.1.4) and Manual of Contract Documents for Highway Works (MCHW), Volumes 1 and 2.

Regulations

2 Construction (Design and Management) Regulations 2007
Construction (Design and Management) Regulations (Northern Ireland) 2007
Information in this Certificate may assist the client, CDM co-ordinator, designer and contractors to address their obligations under these Regulations.
See sections: 3 Description (3.3) and 4 Delivery and site handling (4.2 and 4.3) if applicable.

Readers are advised to check the validity of this Certificate by either referring to the BBA's website (www.bbacerts.co.uk) or contacting the BBA direct (Telephone Hotline 01923 665400).

Figure 9 Example of a BBA Certificate [3]

These third party accreditations are aimed at ensuring that specifiers and end users understand what the system is, how it works, and what other components it typically may require. They often validate testing data and assign appropriate partial factor values to assist in the design of systems of which the geo-component forms a part.

There is still a great deal of ongoing product development and improvement within the Geosystems industry, and the future growth of the sector seems assured especially given the growing importance of sustainability in client and consultant organisations.

Figure 10 Geotextile encased column [9]

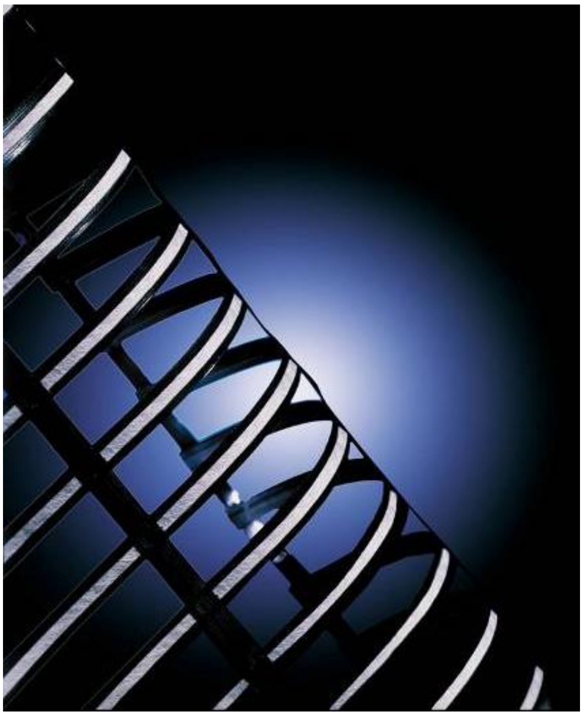

Figure 11 Geogrid with drainage channel [11]

Figure 12 Tri-axial geogrid for soil reinforcement [19]

Figure 13 Geotubes used for coastal erosion and sludge drainage applications [18]

2.3 Geosystems explained

The definition of the term Geosystem (given previously in this document), indicates the three fundamental components which make up the system, namely:

- soil;
- a geo-component; and
- engineering input.

To develop a greater understanding, each of these individual components is described in more detail below.

2.3.1 Soil

This term can mean different things to different people with respect to individual Geosystems. Many think of soil as the resource in our gardens which supports plant growth. However, in the context of civil engineering the term has a more generic meaning encompassing a wide range of unconsolidated materials, from weathered rock through to soft clay sediments, and even recycled materials used for backfill. The concept of 'reinforced soil' is fundamental to a number of Geosystems currently in use.

Figure 14 Granular fill material [4]

Figure 15 Mixed cohesive and topsoil fill [4]

2.3.2 Geo-components

Engineered geo-components come in a wide range of shapes, sizes, materials, colours and configurations, all of which provide a specific function within an individual Geosystem. There may well be more than one geo-component within any given Geosystem.

Many geo-components are manufactured from steel and polymers; others involve timber and concrete (reinforced and un-reinforced), as well as from natural fibre products such as coir or jute.

The geo-components of Geosystems most commonly take the form of reinforcing meshes, straps or strips, made from steel or polymers, which are connected to various facing elements or panels which provide a hard-faced or green-faced retaining structure or slope.

It may seem counter-intuitive that so many geo-components are manufactured from materials which themselves have high levels of embodied carbon. However it should be noted that the amounts of these materials used in a Geosystem are substantially less than in traditional ground engineering solutions employing steel or concrete elements.

The following photographs (and those within the Jargon Buster in Appendix C), illustrate some of the range of geo-components available in today's Geosystems.

Figure 16 Block and geogrids [11]

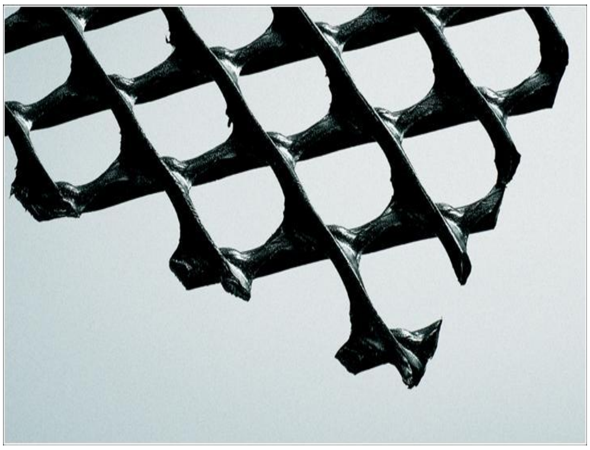

Figure 17 Geonet [10]

Figure 18 Geogrid [9]

2.3.3 Engineering Input (in this context referring primarily to design and technical expertise)

Engineering input is arguably the most important aspect of a Geosystem. Without an appropriate level of technical input it can be difficult for the end user to determine what type of Geosystem will be best suited to the unique set of conditions at any particular site. It is also important that the chosen Geosystem be designed and specified by professionals familiar with the process and using the appropriate design guidance.

At any site there will be a range of physical and aspirational criteria which have to be considered in the selection process. Some of the key criteria are set out below.

- **Ground conditions at the site.** These include: the founding materials under the proposed structure, potential for re-use of site-won materials, and the presence or absence of groundwater.

- **Geometric limitations.** The allowable space for any particular structure may have a bearing on what is ultimately selected. The width of any Geosystems adopted should be treated as a critical consideration, since construction delays may be caused if the correct plant is not available, such as mini-excavators or long reach excavators.

- **Aesthetic finish.** Differing aesthetic finishes are available, including hard-faced, vegetated, terraced or more bespoke solutions.

- **Environmental aspirations.** There may be clear guidance from the end client as to what they wish to see with respect to engineered solutions and their respective carbon footprint.

Figure 19 Site assessment of ground conditions is essential [11]

Figure 20 The chosen Geosystem should be appropriate for the available working space and any other restrictions [11]

Figure 21 Vegetated 'green' finish [9]

Figure 22 Hard faced block finish [14]

A number of geo-component suppliers offer in-house design services (including detailed designs and construction drawings) to an indemnified design level to enhance their product offerings. Manufacturers of individual geo-components generally offer technical advice and guidance on their products, but without providing any warranties or liabilities.

It can therefore be of great benefit to the end user to have some degree of other professional technical input to help to determine if the designs proposed by manufacturers or suppliers are accurate, applicable and in accordance with the relevant design codes or guidance, along with the environmental aspirations which govern any particular project.

Geosystem also lend themselves to designing for de-construction. They are inherently recyclable and their component parts may be re-utilised, (with the exception of some geo-components which will have to be considered un-usable due to the undoubted changes in their engineering characteristics as a consequence of their previous use). The need for such future deconstruction and the merits of the individual Geosystems available should be considered during the site specific selection process.

In practice the process of using a design from a manufacturer or supplier will depend on the size of the project in question and the nature of the contractual relationship between the client, contractor and design consultant with respect to risk, design responsibilities and any collateral warranties or guarantees ultimately required.

Figure 23 Midland Quarry; Nuneaton. Arguably the largest Geosystem structure in the UK. Formed of reinforced soil utilising a blend of site won materials and an imported 'waste' foundry sand as the backfill [16]

2.4 Current use of Geosystems in the UK

Within the civil engineering sector the current levels of awareness of both Geosystems and what they can offer with respect to sustainability is relatively modest. This might be seen as surprising given the levels of direct marketing and advertising carried out by manufacturers and suppliers of geo-components. There are also numerous articles in the trade press highlighting the benefits that can be realised by the incorporation of Geosystems into projects, from both an environmental and cost perspective.

Despite this, use of these types of ground engineering solutions is not increasing in the UK as rapidly as in other countries. A contributory factor may be inflexibility on the part of some industry sectors, and an unwillingness to amend seemingly rigid design policies or standards to allow consideration of Geosystems in place of more traditional 'tried and tested' techniques. Specific product based case-by-case approvals often take a prohibitively long time to obtain.

Figure 24 Bessy Gill railway embankment stabilisation [8]

Although the preceding point may well have an impact on the opportunities available, arguably a larger contributory factor is the lack of a genuine understanding of how Geosystems actually work.

This can lead both design consultants and construction contractors to feel uncomfortable in carrying out the detailed design of these types of structures, instead relying on the in-house design capabilities and undoubted experience of the manufacturers and suppliers of the various geo-components. Alternatively the use of a specialist Geosystem design consultant may bring benefits to all parties concerned as they can apply their specialist engineering and geo-component knowledge to the Geosystem design.

The current usage of Geosystems is, however, exceptionally diverse and reaches into many areas of the civil engineering sector with application areas including retaining walls, steepened slopes, drainage, the improvement of soft ground and existing slopes as well as the construction of earthworks, roads and pavements.

Figure 25 M6 Extension, Guardsmill; used high strength, low strain uni-axial geogrids to construct embankments [4]

3.0 The Business Case

A key advantage of solutions employing Geosystems is often to be found in the generally significantly more efficient use of resources compared to traditional civil engineering ground solutions, particularly those using concrete or steel. This has the potential to deliver very substantial financial (time and cost) and environmental benefits. These are considered below and demonstrated in the various case studies which support this guidance document.

With the growing emphasis on sustainability within the construction industry it is an opportune time to demonstrate how Geosystems can reduce the carbon footprint of construction projects, or elements thereof, when compared to the more traditional methods favoured in the past, as well as delivering social benefits.

It is also worth highlighting that there is often a direct correlation between a reduction in the carbon footprint of a project or element thereof, and the overall cost of the same. This correlation can be clearly seen within the individual case studies within this document.

3.1 Financial benefits

- **Reduced cost of materials imported.** Lower volumes of materials, both the engineered geo-component element and the bulk fill, are generally required in a Geosystems solution. Material purchase costs and transportation are key areas of cost savings.

- **Reduced cost of wastage.** Through allowing re-incorporation of existing lower specification soil on site, the costs of disposal arising from transport, landfill tax, gate fees and charges are reduced.

3.2 Environmental benefits

- **Reduced environmental carbon footprint of materials imported.** Many ground engineering solutions employ materials with high embodied carbon and energy, for example reinforced concrete or steel in retaining walls. Whilst the engineered geo-component element of a Geosystems solution may have similarly high levels of embodied carbon, (on a weight by weight basis), the volumes of materials used, and therefore the overall solution, would typically have a considerably (and sometimes dramatically) smaller carbon footprint.

- **Reduced cost of wastage.** Allowing the re-incorporation of existing lower specification soil on site directly reduces off-site waste disposal, which accounts for so much of the volume of material sent to landfill each year in the UK. This often also directly reduces the need for equivalent imports of bulk fill, resulting in attendant environmental savings from reduced transportation.

Figure 26 Concrete or steel geo-components can often produce environmentally viable Geosystems even though they have potentially high embodied carbon themselves [15]

3.3 Socio-economic aspects

Increased efficiency can certainly benefit the local and wider community, most notably by reducing haulage, with associated reductions in congestion, noise and air pollution. Geosystem solutions can also offer a wider range of aesthetic options, for example in 'softer' green-faced walls providing potential spin-off benefits to biodiversity and more appropriate landscaping.

3.4 Policy and legislation

In addition to the Corporate Social Responsibility benefits to stakeholder organisations involved in ground engineering, Geosystems can directly address important issues increasingly emphasised in planning policy and legislation. This includes the avoidance of waste, and its use as a resource, which is encouraged in Planning Policy Statement 1 and Minerals Policy Statement 1, which encourages the use of alternatives to primary aggregates.

Figure 27 Geosystems often provide simple solutions to meet key environmental constraints [11]

4.0 Application Areas

4.1 Steep Slopes and Retaining Walls

The use of reinforced soil Geosystems within steepened slopes and retaining walls is one of the most common forms of Geosystem seen within the UK. The particular Geosystems which fall into this category include the following.

- Reinforced soil slopes: non-wrap around face for < 45° angle. Almost always with a vegetated or soft landscape finish.
- Reinforced soil slopes: wrap around face for face angles between 45° and 70°. Often vegetated if wrap around type, or otherwise a stepped hard faced system can be employed.
- Reinforced soil slopes: hard faced systems for > 70° angle. These forms of construction are deemed as walls by the HA, and as such hard faced systems are usually adopted.
- Steel and polymeric reinforcement associated with all the above possible solutions.

Figure 28 Gabion and Crib gravity walls An example of a vegetated reinforced soil slope [9]

Examples of this form of construction can be seen throughout the UK. Although at first sight they may not be easy to differentiate from conventional hard faced solutions or naturally occurring vegetated slopes they are delivered in a different way.

These particular types of Geosystem again offer great opportunity for a reduction in carbon footprint as they can readily enable the re-use of site won materials or the incorporation of recycled or modified fills. They can also allow the more rapid construction of a less conventional, but no less valid, alternative to a more tried and tested solution such as a reinforced concrete retaining wall or steel sheet piles.

Figure 29 Geosystems may not be easy to identify from conventional solutions [15]

It should be noted that the manufacturers of geo-components often go to great lengths to develop particular forms of product to meet perceived market demands or particular products which would satisfy an existing design constraint.

Figure 30 Concrete Crib gravity retaining wall [15]

An example of this would be the development of geogrids which incorporate micro-drainage channels within their individual straps to enable cohesive fills which are a few % wetter than their optimum moisture content to potentially be utilised for reinforced soil applications without necessarily requiring modification. (See **Figure 11** Geogrid with drainage channel [11]).

However where these types of fill are modified through the addition of lime, the resultant high level of alkalinity can conflict with the use of some polymeric geogrids. Manufacturers have responded by offering geogrids made with polymers which have a much higher tolerance to elevated pH levels.

These forms of reinforced soil slope Geosystems encourage and readily facilitate the re-use of site won materials, giving them strong environmental credentials. The ability of a reinforced soil Geosystem to adapt to the use of locally available secondary aggregates, by-products or spoil can be demonstrated by the use of the following materials which are locally common in different parts of the UK.

- Red Blaise in the central belt of Scotland.
- Slate waste in Wales, Cumbria and the Southwest.
- China clay washings in Cornwall.
- Chalk tailings in southeast England.
- Pulverised Fuel Ash (PFA) nationwide.
- Foundry sand in the English Midlands.

Figure 31 Blaneau Ffestiniogg, Wales. Temporary road diversion formed from wrap around reinforced soil slopes utilising locally available waste slate material as a backfill [5]

Case Study – Hunter's Lane

- *In the development of Hunters Lane Household Waste and Recycling Centre, a granular fill reinforced with galvanised steel strips was used in place of more traditional steel sheet pile wall for the refurbishment of car park retaining walls.*
- *By using a Geosystem in place of the sheet piles, risks to nearby structures associated with ground vibrations were minimised. Additionally, using the Geosystem wall combined with a geo-component in place of sheet piles, substantial cost and carbon savings could be realised.*

4.2 Ground Stability Applications

The use of geo-components in ground stabilisation is a well established technique, and one which continues to develop through geo-component innovation. There is also a clear demand from clients to be more environmentally friendly by causing less disturbance to the immediate eco-systems, and by utilising more of those materials that are locally available (and importing less to site), thereby minimising the project carbon footprint.

Typical geo-components used to create ground stabilisation Geosystems are as follows.

- **Prefabricated Vertical Drains**; PVD's (Band drains). Used to construct embankments over soft compressible ground in a phased manner.
- **Horizontal drains.** Can be inserted into cut slopes to assist in reducing or controlling the groundwater levels within the slope, and hence improving slope stability.
- **Soil nails and grounds anchors**. Used primarily to enable the stabilisation of existing embankments or cuttings where the slopes have to be over-steep, and therefore require additional stabilising forces.
- **Basal reinforcement**. These take the form of woven or knitted geosynthetics, often used in conjunction with PVD's (band drains) and a basal drainage layer, to enable a more rapid construction programme. The drainage layer can double up as a safe working platform to enable the safe installation of the band drains.
- **Geotextile Encased Columns (GEC).** This type of ground improvement fulfils multiple functions including acting as a bearing pile, providing ground improvement and assisting vertical drainage due to its permeable nature. The large diameter of the GEC's can provide more rapid settlement when compared to traditional PVD's and offers almost immediate bearing support for the construction activities above.

Figure 32 PVD geocomposites provide effective ground improvement solutions [8] & [4]

Figure 33 Vegetated Geosystems can become hidden [11]

Figure 34 Basal reinforcement and a 6C stone drainage layer being installed to enable future construction of road embankments [9]

Case Study – Houten GEC's

- *Huesker's Ringtrac GEC's were used in Houten as an alternative to piles when creating a land platform adjacent to a housing development which was sensitive to the use of driven piles.*

- *A substantially reduced project carbon footprint was achieved by adopting the GECs through allowing use of locally-dredged sand material in contrast to high embodied energy pre-cast concrete piles.*

- *Corresponding cost savings were also very significant, extending to more than £50,000 on a project of £200,000 value.*

4.3 Road and Pavement Applications

The use of geo-components within the roads and pavement sector is finding increasing favour, especially when whole life costing is of critical importance. The incorporation of geo-components in the form of reinforcement grids and meshes, geotextiles and geocomposites into both the asphaltic layers and the granular sub-base of paved roads is becoming the norm.

The choice of the depth at which a road should be reinforced depends on whether the aim is to extend pavement life by limiting reflective cracking, or to address the ultimate capacity of the road in the context of poor ground conditions.

The following list demonstrates the range of options typically available.

Paved Roads (with an asphaltic surface)

- The incorporation of a geo-component into the granular sub-base or capping layer can reduce the depth of these materials by 30% to 40%. Reinforcement in the form of steel mesh or polymeric geogrids is often preferred within these granular layers. The reinforcement not only acts to increase the bearing capacity of the sub-base layers, but can also mitigate against the propagation of cracking from the base of the road to the asphaltic (bound) layer of the pavement itself.

- Reinforcement of the asphaltic or bound layers, can increase the life of the surface layers, again by contributing to a strengthening of the bound layers. Such strengthening increases their ability to resist cyclic fatigue, thermal stresses during extremes of winter and summer temperatures, as well as increasing resistance to near-surface crack propagation. For this application the geo-component comes in the form of, polymeric, steel or glass grids, polymeric or glass geotextiles and geo-composites.

- There are often many alternative geo-components to consider in any application area. These need to be assessed against a number of criteria which have to be considered before selecting the preferred one. With particular regard to the reinforcement of asphalt pavements the following questions will likely need to be considered:

  - What is the depth of surface course overlay?
  - Can a tack coat of bitumen be applied?
  - Are physical fixings into the base layer possible?

Figure 35 Asphalt reinforcement [19]

Unpaved Roads

- Unpaved roads share some of the above characteristics, but lacking any asphaltic surface the exposed granular layers form a running surface. They are often used for temporary haul roads on sites, or as access tracks which have low volumes of traffic, such as for wind farms or service roads adjacent to pipelines or other infrastructure.

- The use of geo-component reinforcement at the base of the granular layers is again standard and helps to keep the depths optimised. Additional reinforcement often in the form of bi-axial or tri-axial reinforcement can reduce rutting where heavy plant and equipment may be involved.

Figure 36 The reinforcement of unpaved roads often utilises bi-axial geogrids [19]

Figure 37 Steel mesh reinforcement being usedon Abingdon Road, Oxford [11]

Case Study – Abingdon Road, Oxford

- *A section of the heavily used A4114 Abingdon Road in Oxford was reconstructed using a range of geo-components; namely Maccaferri Road Mesh and Colbond Enkagrid TRC.*

- *The design allowed a reduction in the construction depth of the pavement by some 350mm whilst maintaining its inherent strength and durability. The resulting benefits were:*

  - *preserving underlying shallow archaeological remains;*
  - *avoiding relocation of underlying shallow services; and*
  - *reduced thickness of bituminous layers.*

- *The reduced overall construction thickness delivered a projected reduction of 800 tonnes in waste over a sample 350m section of road, with obvious benefits to the carbon footprint for the project.*

4.4 Other Application Areas

There are many Geosystems which do not readily fit into the preceding categories. However, this does not mean that they are any less important in the wider family of Geosystems, but rather that they have unique applications and are often engineered with one particular feature in mind. Examples would include the following.

- Working platforms for cranes or heavy plant.
- Erosion control of water courses or embankment slopes.
- Geotubes for erosion protection or filtration applications.
- Separation and protection geotextiles in transport or marine applications.
- Landfill applications, where a range of geo-components may be utilised in combination to achieve protection, filtration, separation and drainage in a composite layer comprising a bespoke sequence of products.

Case Study – M25 back of wall drainage

- *Widening of a section of the M25 between Junctions 12 and 15 included a requirement for a retaining wall structure allowing adequate drainage through it. The initial design option for the wall included 300mm of granular fill for back of wall drainage.*
- *A solution employing a geocomposite material behind the wall, as an alternative to the 300mm granular drainage layer, was proposed and accepted. The incorporation of the drainage geocomposite also simplified construction and backfilling.*
- *Around 10,000m2 of Naue Secudrain was applied to a 1km section of the motorway retaining wall. Despite import of the geo-component from continental Europe, the final design delivered significant financial and environmental cost savings over the original design option, principally through requiring less granular drainage backfill.*

Figure 38 Drainage Geocomposite; M25 Widening [12]

5.0 Selection of Appropriate Geosystems

The process of selecting the most appropriate Geosystems is largely dependent on the criteria for the finished element of the work for which it is required.

For example the aesthetic look of the finished structure may be very important to the client and / or the architect, along with the knowledge that the environmental impact of the chosen system is the most beneficial given the specifics of the particular project. By contrast, the Contractor for the same project may be looking for the most cost effective system which can utilise the site-won fill, providing an easy to construct system which may also bring program and cost savings.

Figure 39 An appreciation of the materials, methods of construction and site constraints can be invaluable in the selection of Geosystems [5]

5.1 Technical Considerations

An early technical evaluation of the suitability of a range of Geosystems should be carried out, because technical considerations will often eliminate a number of options. This exercise should be carried out with particular regard to the following factors.

- The foundation materials under the proposed structure.
- The suitability of the intended backfill materials to be used.
- The compatibility of these backfill materials with the various geo-components which will make up the various Geosystems.
- Ease of construction, access, plant and labour requirements, also considering the need for manual lifting / handling, and PPE requirements.
- CDM issues, regarding safety to the workforce and the general public during and after construction.
- Post-construction operations and maintenance needs and methods of repair in the event of damage from impact, fire or vandalism.

Such an initial review will greatly assist any subsequent evaluations which would consider economic, environmental and aesthetic considerations.

5.2 Economic Considerations

The economic assessment of alternative Geosystems can be problematic for those who are unfamiliar with the process of comparative pricing of such systems.

Often the 'bottom line' financial comparison of the price of the geo-components is made with little understanding of the subsequent construction pros and cons which apply to the different Geosystems available. Some Geosystems demand a semi-skilled workforce to construct them whilst others can be readily undertaken by an unskilled labour force.

It can be this underestimation of the time, labour and secondary materials associated with the different Geosystems which can often lead to uneconomic systems being selected. There are many cases where the component parts of the selected Geosystem are delivered to site without the full extent of the true cost in term of monetary and time costs being apparent.

This type of oversight can be avoided by requesting system specific method statements from the geo-component suppliers, so that a better understanding of the requirements of the particular systems can be appreciated and accounted for.

Another important factor mentioned in the previous section is whether a particular Geosystem provides the option of using lower specification fills. This option, if realised, can account for large cost and environmental benefits, but must be entered into with due regard to the technical considerations. However this is an area where decisions need to be based on engineering considerations and careful assessment of site won or recycled fills should be made. The quality control of these types of fill and their correct compaction and supervision all need to be considered in detail.

5.3 Environmental Considerations

This is perhaps the most important aspect of Geosystem selection, especially given the aims of this guidance document. It has been highlighted previously within this document that there is a growing awareness of environmental issues both within the general public but also within client organisations, contractors, central and local government.

The concept of carbon footprint has become commonplace, and the construction industry has also embraced the sentiment in recent years with an emphasis on the sustainability of construction.

Figure 40 Environmental decisions regarding the selection of Geosystems need to be informed ones [9]

Whatever the terminology used, the same end result is desired, which is to minimise the environmental impact by attempting to minimise the embodied carbon and energy within specific engineered components, or replacing them completely with an alternative option such as a Geosystem.

This document has demonstrated, through verified industry case studies, how the use of Geosystems, which offer undeniable environmental benefits via substantial reductions in their associated embodied carbon, can provide alternatives to more traditional engineered structures.

6.0 Sustainability and Geosystems

6.1 Evaluating the Carbon Footprint

Understanding the potential carbon footprint of alternative design and construction scenarios is essential to allow informed selection of the most efficient ground engineering option, and to establish whether a Geosystems approach could provide advantages over the conventional solution.

This understanding inevitably requires a site-by-site, element-by-element approach, considering the construction programme, the nature of the ground engineering challenge, the available materials on site and nearby, site supply logistics and site layout. However, experience in the use of Geosystems demonstrated in the case studies supporting this guidance document identifies several key areas where these systems are likely to have pivotal environmental benefits.

- Reduced volumes of excavation, perhaps due to a reduced footprint of the ground engineering structure producing a reduced need for engineered backfill.

- Reduced material wastage by the introduction of an engineered geo-component element permitting the re-use of lower grade materials that may be available on site or in the locality.

- Reduced consumption of higher grade construction aggregates by using existing lower grade site-won or nearby materials through the introduction of the geo-component.

- Reduced construction haulage from lower volumes of material import and waste export.

- Reduced usage of high embodied carbon materials, most notably steel, concrete and primary aggregates.

Figure 41 The construction sector can make a very large contribution to reducing the impact we have on the environment [5]

Additional resources

1. Building Research Establishment, BRE Report 424, 2001 - Building on Fill: Geotechnical Aspects.
2. British Standards Institution, BS8002 - Code of Practice for Earth Retaining Structures.
3. British Standards Institution, BS8006 - Code of Practice for Reinforced Soils and Other Fills.
4. Autotrader, Trucks: Report in April 2006 discussing the fuel efficiency and average consumption of all UK truck manufacturers. The report included all sizes of truck including tipper/dumper trucks usually seen on sites. (http://www.autotrader.co.uk/TRUCKS/trucks_news_2006.jsp)
5. Hong Kong Geotechnical Engineering Office, Geoguide 6, 2002: Guide to Reinforced Fill Structures and Slope Design.
6. Transport Research Laboratory, Report 341, Highway embankments over soft compressible alluvial deposits: guidelines for design and construction.
7. CIRIA, Report C637, 2005 – Soil Nailing: Best Practice Guidance.
8. CIRIA Report C708, 2007 – Use of Vegetation in Civil Engineering.
9. CIRIA Publication SP123, 1996 – Soil Reinforcement with Geosynthetics.
10. Highways Agency Design Manual for Roads and Bridges Publication HA68/94: Design Methods for the Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques.
11. Carbon Neutral Plant a Tree for Me: Carbon Offset Tree Planting (www.carbonneutralfuel.co.uk).
12. Defra, Guidance to Defra's GHG Conversion factors for company reporting: Document produced by Defra to help businesses to calculate their energy usage. This includes calculations and values of CO2 of emissions associated with different modes of transportation. (http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf).
13. SPON'S Estimating Cost Guides: SPON'S produce a series of costing guides. These guides include publications for civil engineering, building elements and material prices.
14. University of Bath & Carbon Trust, Inventory of Carbon & Energy (ICE) Version 1.6a: Research Document undertaken by the University of Bath's Department of Engineering, with support from the Carbon Trust and EPSRC. The report is an inventory of embodied energy and carbon coefficients for building materials. (http://www.bath.ac.uk/mech-eng/sert/embodied).
15. WRAP Gate Fees Report 2008, comparing the costs of alternative waste treatment: Pilot study undertaken by WRAP to collect accurate information on landfill tax and gate fees with in the UK. The report gives average costings for different treatments of waste material. (http://www.wrap.org.uk/index.html).

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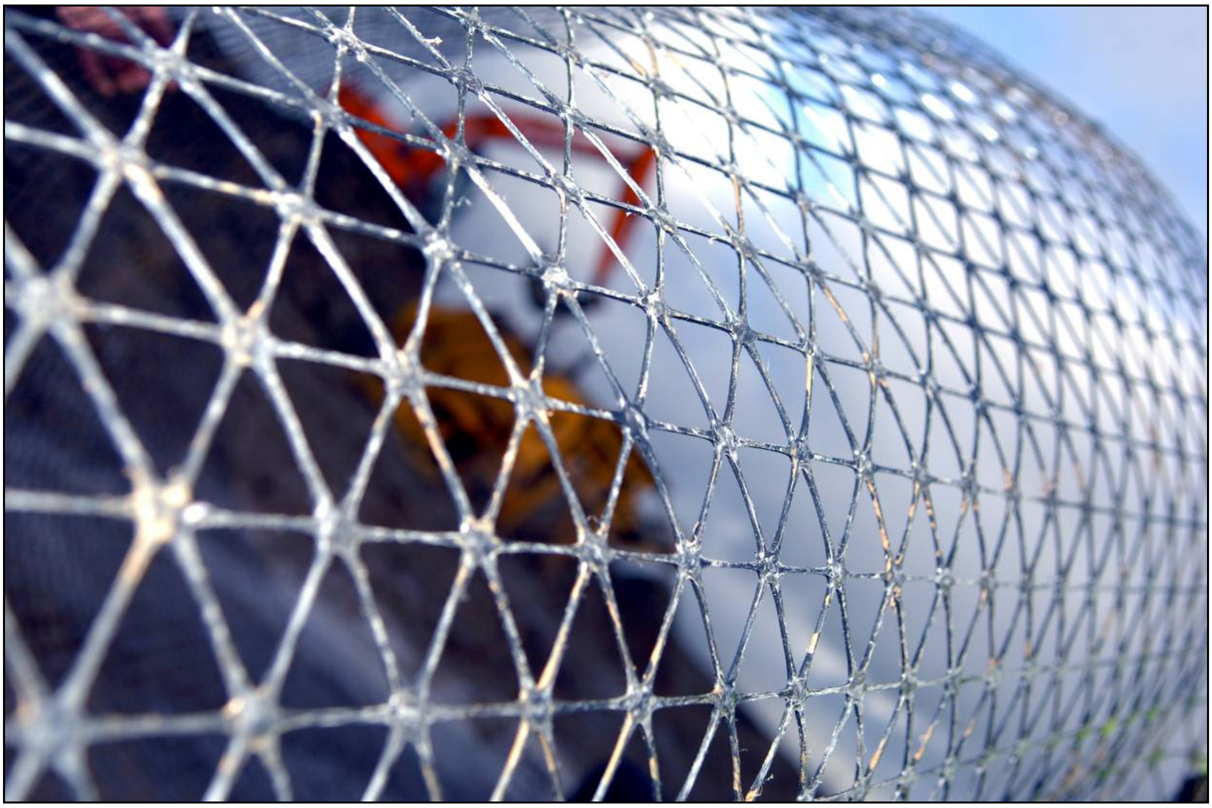
www.wrap.org.uk

Jargon Buster



[19][1]

[1] *Photo credits can be found in the Acknowledgments section of the report 'Sustainable Geosystems in Civil Engineering Applications'*

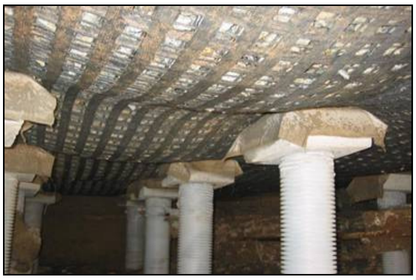
Basal Reinforcement

The incorporation of geogrids or geotextiles at the base of embankments constructed over soft, compressible ground. Often used in conjunction with Prefabricated Vertical Drains (PVDs) or band drains, or other forms of ground improvement.

[9]

Basal Reinforced Platforms (BRPs)

The use of high strength geotextiles or geogrids to transfer vertical and lateral embankment loads onto a piled foundation. Also known as Load Transfer Platforms (LTPs).



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Band Drains

Geocomposites formed of a hollow cored, geotextile wrapped drainage element (geonet) inserted vertically into soft ground to speed up the consolidation process. Also known as Prefabricated Vertical Drains (PVDs).

[4]

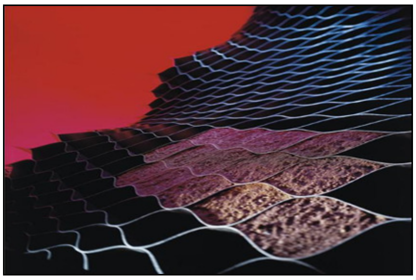
[8]

Bodkins

HDPE strips used by some geosystems to connect geogrid to geogrid or a facing unit to a geogrid.

Cellular Erosion Control Products

Strips of polymeric sheet creating three-dimensional networks in a honeycomb or cellular pattern. These systems are usually used to allow a topsoil layer to be secured to a steep slope to enable successful vegetation and are typically filled with soil or concrete (sometimes referred to as Geocells)



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Erosion Control Netting

Woven or knitted natural fibre products (coir or hemp typically), used for short term erosion control measures before the establishment of permanent vegetation.

[11]

Gabions

Woven or welded wire mesh baskets, (often with wires coated in a plastic sleeve to extend lifespan), typically used to create mass gravity retaining walls, river revetments and other erosion control structures.

[11]

[11]

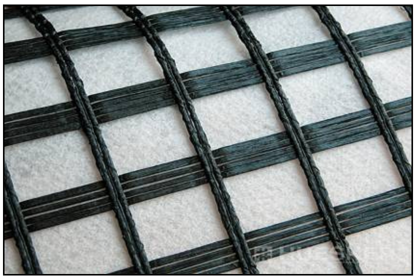
Geocells

A deep (1m) layer of interconnecting strips of geogrids filled with granular material to create a stiffened basal layer which can be used to control differential settlement under embankments constructed on compressible ground.

Geocomposites

- Drainage
- Waterproofing

A generic description for products made from any combination of two or more geocomponents to fulfil a specific function or functions. Examples being for drainage applications or separation and reinforcement functions.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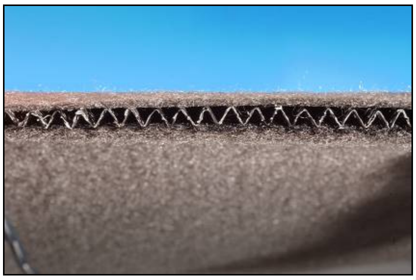
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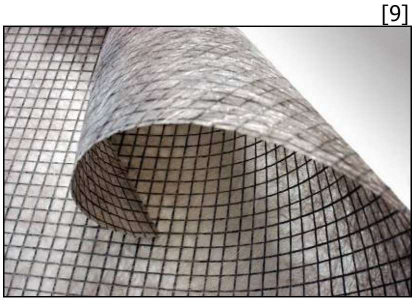
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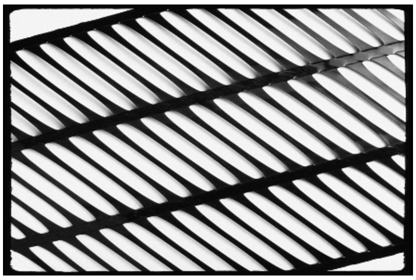
Geogrids, Grids

(Bi-axial, Uni-axial, Tri-axial)

Open grid-like meshes formed of different polymers. Usually produced with a range of strengths in either a biaxial orientation (meaning the same strength in both directions), or uni-axial, (meaning main strength in one direction only), or Tri-axial (with a honeycomb appearance). The apertures within the grids may therefore be square, rectangular or triangular.


[9]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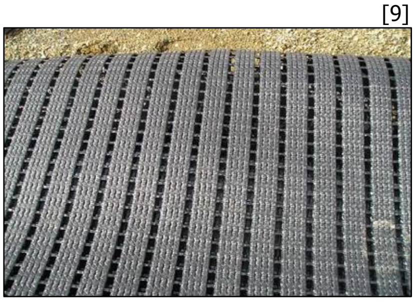
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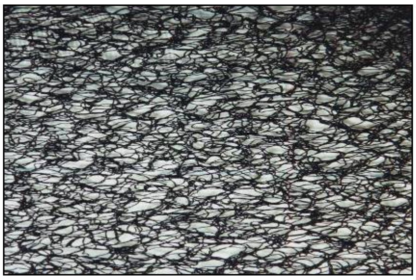
3D Geomats

An extruded polymer (plastic) which is randomly entangled to produce a 'brillo pad' type mat. A fine mesh can also be used in an undulating manner and bond to either another mesh or geotextile.



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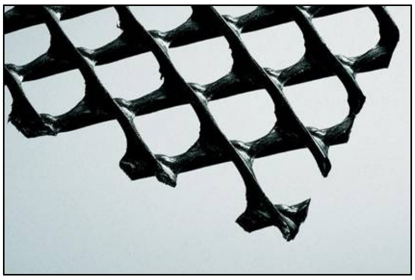
Geonets

Two sets of coarse, parallel extruded polymeric strands which cross at an acute angle. Has an open grid-like appearance



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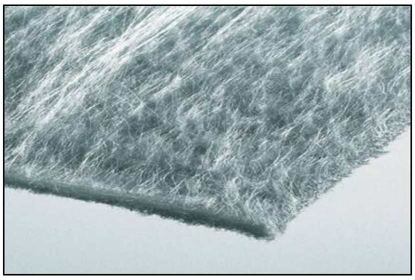
Geotextile

- non-woven,
- needle punched
- thermally bonded
- woven tape

Continuous sheets of woven, non-woven, stitch-bonded or knitted fibres or yarns. Geotextiles have similar properties to fabrics and are flexible and permeable.



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Geotextile Encased Columns

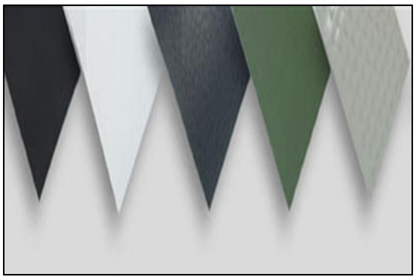
A continuously, radially, woven geotextile sock made from a variety of polymers. These socks form encased stone columns when filled with compacted sand, gravels or crushed rock for use in very soft soil where conventional ground treatments cannot be utilised.

[9]

Membranes

Flexible continuous sheets of one or more synthetic material which are relatively impermeable. Membranes have to be site glued or welded to ensure waterproof function.

[9]



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Prefabricated Vertical Drains (PVDs).

See Band Drains

Reinforced Soil

The generic term which describes the incorporation of a geo-component into a soil material thereby increasing its inherent strength.

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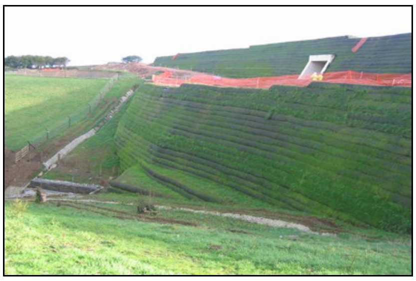

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Segmental Block Wall (also known as Modular Block Wall)

Used to construct near vertical hard faced systems. These walls can be either designed at low height as a gravity wall or for use for greater heights with the incorporation of a polymeric or steel reinforcement component between the blocks, extending into the retained soils behind

[19]

[14]

[11]

Steel Faced Systems

The use of steel meshes (rectangular aperture or hexagonal woven meshes) to form sub vertical and vertical reinforced soil structures. Often with stone facings used behind the mesh facings, or if temporary lined with geotextile.

[9]

[11]

[11]

Steel Reinforcement

In the context of Geosystems steel reinforcement comes in the form of steel strips typically used to reinforce concrete face panel systems, or in reinforced soil slopes by the use of woven, polymer coated hexagonal meshes.

Vegetated Face

The process of 'greening' the face of a geosystem by planting or seeding the topsoil retained behind the front face. Usually describing a wrap around reinforced soil slope face, or sub-vertical steel faced systems.

Vertical Hard Faces Systems

The use of split faced concrete blocks, gabion or steel mesh faced composite systems to construct 'walls', which are defined as being steeper than 70°.


[14]


[11]


[19]

Working Platform/Piling Platform

The construction of granular platforms to facilitate initial site access or the provision of a stable working environment for the use of heavy plant to safely install piled foundations, ground improvement or to operate cranes and other construction vehicles. Geotextiles, geocomposites and geogrids are often incorporated into the granular materials to strengthen them.

PA

Abbreviation for **Polyamide** used in the specification of geocomponents, normally for geotextiles.

PET

Abbreviation for **Polyester** used in the specification of geocomponents, normally for geogrids and geotextiles.

Polymers / Polymeric

Commonly known as plastics.

PP

Abbreviation for **Polypropylene** used in the specification of geocomponents, normally for geogrids, drainage geocomposites and geotextiles.

PVA

Abbreviation for **Poly Vinyl Alcohol** used in the specification of geocomponents, normally geogrids.

HDPE

Abbreviation for **High Density Polyethylene** used in the specification of geocomponents, geomembranes and geogrids.

LDPE

Abbreviation for **Low Density Polyethylene** used in the specification of geocomponents, normally geomembranes.

Wrap Around Face

- Temporary Shuttering

Wrap around faces are used with reinforced soil slopes where the face angle is sub-vertical (typically less than 70°). The wrap around face is formed from the free end of the embedded geogrid which is wrapped around and up the front face of the individual lifts which are typically between 300mm and 800mm in vertical height. Often temporary shutters are used to form the individual lifts.

[5]

[14]

Geosystems applications suitability selection matrix

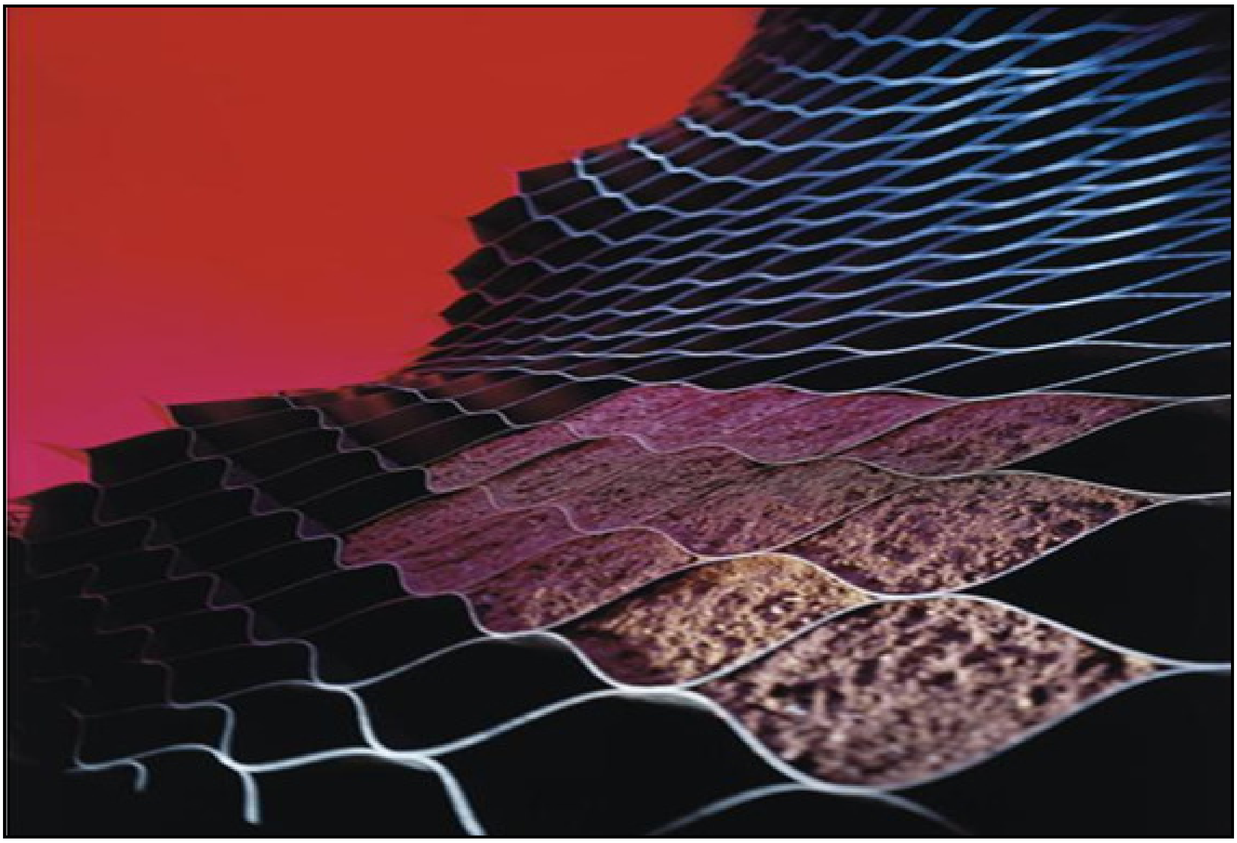
This matrix is intended to provide first pass guidance to identifying the forms of particular Geosystem solution appropriate to a particular application

	Application Area	Reinforced Soil Slopes and Retaining Wall Applications					
Geosystem Description		Slopes < 45°	Slopes > 45°< 69°	Walls > 70° Green Face	Walls > 70° Hard Face	Gravity Retaining walls	Green Face Possibilities
Gabions						✓	✓
Geogrids		✓	✓	✓	✓		✓
Steel Mesh / Straps Systems			✓		✓		✓
Segmental Block Walling					✓	✓	
Erosion Control Products		✓					
Wrap Around Face Systems			✓	✓			✓

	Application Area	Ground Stability			Ground Improvement	
Geosystem Description		Basal Reinforced Piled Embankments	Basal Reinforced Embankment	Void Spanning	Positive Drainage	Intrusive Techniques
High Strength Geogrids or Geotextiles		✓	✓	✓		
Band Drains (PVD's)			✓		✓	
Geotextile Encased Columns			✓			✓
Geocell			✓			

	Application Area	Roads & Pavements & Working Platforms		
Geosystem Description		Temporary Access & Haul Roads	Permanent Sub-Base Reinforcement	Asphalt Reinforcement
Geotextiles		✓		
Geogrids		✓	✓	✓
Glass Fibre Reinforcement				✓
Steel Mesh Reinforcement			✓	✓
Geocomposites		✓	✓	✓

Methodology to the CO_2 Calculations



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[1] *Photo credits can be found in the Acknowledgments section of the report 'Sustainable Geosystems in Civil Engineering Applications'*

Methodology to the CO_2 Calculations

The methodology used to calculate the embodied CO_2 of the material in each case study was based on the Inventory of Carbon & Energy (ICE) document produced by Bath University, with the Carbon Trust. The document provides the embodied energy and the embodied CO_2 of many every day materials. The embodied CO_2 of a material is a calculated value of the quantity of carbon derived due to the extraction, processing and transportation of the material to the product. This value is typically expressed as the mass in kg of embodied CO_2 from producing 1 kg of material, shown as kg CO_2 /kg. It must be noted which version of the report was used as it is continually being expanded and re-published. The values used were correct at the time of the project been undertaken and were taken from report version 1.6a.

One observation of the values published is, the more processing required to produce the material, the higher the embodied CO_2 is. For materials such as virgin metals, the embodied CO_2 is much higher than that of recycled metals as much more energy is used in the extraction process from ore than from recycled materials. This must be taken in to consideration when reviewing some of the geosystem methods used, as some of the metal based geocomponents may appear to have very high embodied CO_2 values compared to others, but this is likely to be due to only virgin metals been used for the products.

When undertaking the CO_2 calculations it is necessary to ascertain the weight and material type of each component part to ensure the calculations were as accurate as possible. Most of the necessary information regarding the geocomponents was present within the technical information sheets. However, on a few occasions some assumptions had to be made as the information was not available, but in such instances, a suitable industry guide was used such as SPONS.

It must be noted that the report has not included the CO2 associated with the production of any of the geocomponents. Due to the sensitive nature of the production methods and processes associated with the different geocomponents, it was not possible to collect the data required to assess the CO_2 produced during manufacturing. This must be kept in mind when looking at the total CO_2 values for the Geosystem design methods.

Method 1 – Embodied energy of single material type

To ascertain the carbon footprint of each case study it was necessary to calculate the embodied carbon of the materials being used. This involved several calculations and reference to the ICE document.

The first stage was to calculate the total amount of material used in each component part of the case study. For example if there was a need for 10m^3 of aggregate fill, it would be necessary to calculate the weight of the material (Calculation 1).

Calculation 1

10 x 2.1 = 21 Tonnes

10 = Amount of material m^3
2.1 = Volume to Mass ratio
21 = Weight of material in Tonnes

In order to calculate the embodied CO_2 of the aggregate the weight needs to be converted into kg. The reason for this is because the embodied CO_2 values given in the ICE document are in $kgCO_2$ per kg of material. So the second calculation would be to convert the weight of material in to kg, (Calculation 2).

Calculation 2

21 x 1000 = 21000 kg

21 = Weight of material in Tonnes
1000 = Conversion factor
21000 = Weight of material in kg

For the next stage of the calculation it is necessary to ascertain the embodied carbon per unit mass of each component part from the ICE document; at this point a suitable material from the list needs to be selected. In the case of aggregate, the material in the list named general aggregate is suitable and from the ECO_2 column the value can be taken. The following calculation is necessary to calculate the embodied CO_2 of each of the component parts (Calculation 3).

Calculation 3

21000 x 0.005 = 105 $kgCO_2$

21000 = Weight of material in kg
0.005 = ECO_2 value for General Aggregate from ICE document
105 = Amount of Embodied CO_2 in kg

The final calculation is to convert the ECO_2 value for kg to Tonnes (Calculation 4).

Calculation 4

105 / 1000 = 0.105 Tonnes CO_2

105 = Total ECO_2 of Mesh in kg
1000 = Conversion factor
0.105 = Total ECO_2 of Mesh in Tonnes

The embodied CO_2 of $10m^3$ of aggregate material is 0.105 tonnes. Calculation 1 is not necessary if the material weight in kg or tonnes is known to begin with. This method was applied to all the materials used in both, the traditional and the Geosystem, for each case study. However, if the component part, a geotextile for example, comprises more than one type of material, the method of calculating the products embodied CO_2 requires an additional step, shown in Method 2 below.

Method 2 – Embodied energy of multiple materials in one product

The first stage of the calculation is to ascertain the embodied values for one unit of the material. This involves breaking down each element of the product. For example gabion mesh comprises several different materials, so to calculate the embodied CO_2 of 100m^2 of gabion mesh the first calculation would be to break down the products in the mesh into each component part.

Product component parts

Gabion Mesh:

Steel	- Wire
Zinc -	- Galvanising
Aluminium	- Galvanising

The next stage is to calculate the weight of the material for a known unit area or volume, in this case 1m^2. The total weight needs to be ascertained for each material. The first calculation is to determine the weight of each element of the galvanising from the weight given in the gabion mesh technical document. (Calculations 1a & 1b)

Weight of Materials

Gabion Mesh:

Total weight of wire = 1890 g/m^2
Total weight of galvanising = 245 g/m^2

Calculations 1a & 1b

1a 245 x 95% = 232.75 g/m^2 (Zinc)

1b 245 x 5% = 12.25 g/m^2 (Aluminium)

245	= Total weight of material in grams
95	= Percentage of Zinc for multiple
5	= Percentage of Aluminium for multiple

Steel	- Wire	= 1890 g/m^2
Zinc	- Galvanising (95%)	= 232.75 g/m^2
Aluminium	- Galvanising (5%)	= 12.25 g/m^2

These weight per unit area values are then converted in to kg as the Embodied CO_2 values given in the ICE document are in kgCO_2 per kg of material (Calculation 2a, 2b &2c).

Calculations 2, 2a, 2b & 2c

2 A / B = C

2a Steel: 1890 / 1000 = 1.89 kg/m^2

2b Zinc: 232.75 / 1000 = 0.23275 kg/m^2

2c Aluminium: 12.25 / 1000 = 0.01225 kg/m^2

A = Weight of material in grams
B = Conversion factor g / kg
C = Weight of material in kg

As with method 1 the embodied $CO_2$of each material needs to be calculated. Each of the materials E CO_2 values would be selected form the ICE list as in method 1. In the example of the gabion mesh, the value for virgin metals would be used, as recycled metals are not used within these geocomponents. The third calculation would be to ascertain the embodied $CO_2$of each material component part for the one known unit. (Calculations 3a, 3b & 3c).

Calculations 3, 3a, 3b & 3c

3 C x D = E

3a Steel: 1.89 x 2.83 = 5.3487 kgCO_2/m2

3b Zinc: 0.23275 x 3.86 = 0.898415 kgCO_2/m^2

3c Aluminium: 0.01225 x 11.46 = 0.140385 kgCO_2/m^2

C = Weight of material in kg
D = ECO_2 value for Material from ICE document
E = Amount of Embodied CO_2 in kg

The total embodied CO_2 for one unit area of the mesh is calculated by adding all the CO_2 values of each component part (Calculation 4). Then, the total amount of ECO_2 for 100m^2 of mesh can be calculated (Calculation 5).

Calculation 4

5.3487 + 0.898415 + 0.140385 = 6.3875 kgCO_2/m^2

5.3487 = ECO_2 of Steel for 1m^2
0.898415 = ECO_2 of Zinc for 1m^2
0.140385 = ECO_2 of Aluminium for 1m^2
6.3875 = Total ECO_2 of Gabion Mesh for 1m^2

Calculation 5

100 x 6.3875 = 638.75 kgCO_2

100 = Total amount of mesh m^2
6.3875 = Total ECO_2 of Mesh for $1m^2$
638.75 = Total ECO_2 of Mesh

As in Method 1, the value is then converted to tonnes CO_2 (Calculation 6).

Calculation 6

638.75 / 1000 = 0.63875 Tonnes CO_2

638.75 = Total ECO_2 of Mesh in kg
1000 = Conversion factor
0.105 = Total ECO_2 of Mesh in Tonnes

Method 3 - – CO2 emissions associated with the transport of materials

The final method of CO_2 calculation was for the amount of CO_2 released during the transport of the materials. These calculations included reference to values given by Defra in relation to CO_2 emissions from vehicles. The average fuel consumption for trucks was taken from the manufactures specification documents and truck trader. In this example, the first calculation is to determine the average fuel consumption of a 20 tonne tipper truck in litres (Calculation 1).

Calculation 1

8 / 4.545 = 1.76 miles per litre

8 = Number of miles per gallon of diesel
4.545 = Number of litres in a gallon
1.76 = Number of miles per litre of diesel

The next step is to calculate the total number of miles travelled during the transportation of the material. Each calculation considers both an outgoing and return journey for each load. The example below assumes 5 truckloads of aggregate imported form a quarry located 12 miles from site (Calculation 2).

Calculations 2a & 2b

2a 12 x 2 (outgoing and return journey) = 24 miles

2b 24 x 5 = 120 miles

12	= Miles to site from quarry
24	= Total miles for one load both outgoing and return trips
5	= Number of loads
120	= Total number of miles for aggregate transport

As the Defra values for CO_2 are in litres it is necessary to calculate the number of litres of diesel used from the total mileage using the information from calculation 1 and 2 (Calculation 3).

Calculation 3

120 / 1.76 = 68.18 litres

120	= Total number of miles for aggregate transport
1.76	= Number of miles per litre of diesel
68.18	= Total number of litres of fuel used

Similar to the ICE report, the Defra values are presented as $kgCO_2$ per one litre of diesel. The next calculation is to ascertain the amount of CO_2 produced during the transport the materials (Calculation 4).

Calculation 4

68.18 x 2.630 = 179.3134 $kgCO_2$

68.18	= Total number of litres of fuel used
2.630	= CO_2 value for Diesel from Defra document
179.3134	= Total amount of CO_2 released during transportation in kg

As with the embodied CO_2 calculations, the value is converted into tonnes CO_2 (Calculation 5).

Calculation 5

179.3134 / 1000 = 0.1793134 Tonnes CO_2

179.3134	= Total amount of CO_2 released during transportation in kg
1000	= Conversion factor
0.105	= Total amount of CO_2 released during transportation in Tonnes

A key observation of the calculations is that the most appropriate geosystem method needs to be used for each specific project. No geosystem is more CO2 friendly than others; it depends on available resources and materials on site or within close proximity for each individual site.

Material change for
a better environment

Sustainable Geosystems in Civil Engineering Applications

Axis Business Park Environmental Bund, Liverpool

(Photograph courtesy of TenCate Geosynthetics (UK) Ltd.)

At Axis Business Park, Liverpool, the ability to re-use poor quality site-won material within a major engineered bund produced substantial savings in costs, carbon emissions and wastage.

Axis Business Park Environmental Bund

The Axis Business Park Environmental Bund was constructed to provide a visual screen and to reduce the amount of noise reaching the adjacent residential properties from the 24 hour operations at the warehouse facility which was to be constructed. A smaller bund was already present, but was no longer adequate for the amount of activity proposed. The new bund was commissioned by the main contractors (Bowmer & Kirkland) on behalf of T J Morris, with Capita Symonds as bund design consultant. P C Construction undertook the works, and W A Fairhurst acted as the client's overall scheme design consultant.

Key facts

The environmental bund was required to reduce visual and noise impacts on neighbouring residents. The full bund was 350m long by 9.5m high.

Throughout this case study the alternatives are assessed for a 50m length of bund.

Site-won materials were modified using locally-sourced lime, and combined with a geogrid to create a Geosystem, as an alternative to the indicative design proposal (a gabion wall based on imported granular fill).

The Geosystems approach allowed approximately 4,000 tonnes of site-won soil which would otherwise have been sent to landfill to be used, resulting in:

- reduced construction waste
- reduction in need for imported granular fill
- savings to the project of around 96% of the costs and 89% of the embodied CO2 compared to the more conventional scheme.

Indicative design proposal (for comparison)

The original indicative gabion wall design required the removal of approximately 4,000 tonnes of soil arising from the ground works. This material would have been transported by road and disposed of in a landfill. For calculation purposes, a landfill in the Skelmersdale / Wigan area was assumed (around 13 miles from the site).

The wall required around 1,980 tonnes of granular fill for the gabion baskets, and a further 4,000 tonnes to create a granular wedge and drainage behind them. This fill material would have been sourced from Denbigh in North Wales[1]. At around 49 miles from the site, it was the closest location identified for suitable gabion rock fill. The gabion baskets would also have been delivered by road. The gabion baskets themselves have a relatively high embodied CO_2 value because of the energy-intensive steel used in their manufacture.

When compared with the reinforced soil design, additional fuel for plant and machinery would have been necessary for the construction of the gabion wall design. Both Designs would have required vibrated stone columns (VSC) to improve the base. The VSC have not been considered in either design calculation as they would be equivalent in each case.

Geosystem design

The Geosystem used is illustrated in Figure 1, overleaf.

The chosen Geosystems design was based on the re-use of 4,000 tonnes of material (won from site by surface stripping and lowering of the site to allow for future drainage arrangements), resulting in no waste materials needing to be taken off site. The handling and compaction properties of the soils were improved by combining them with small quantities of lime (approximately 18 tonnes), imported to site for this purpose.

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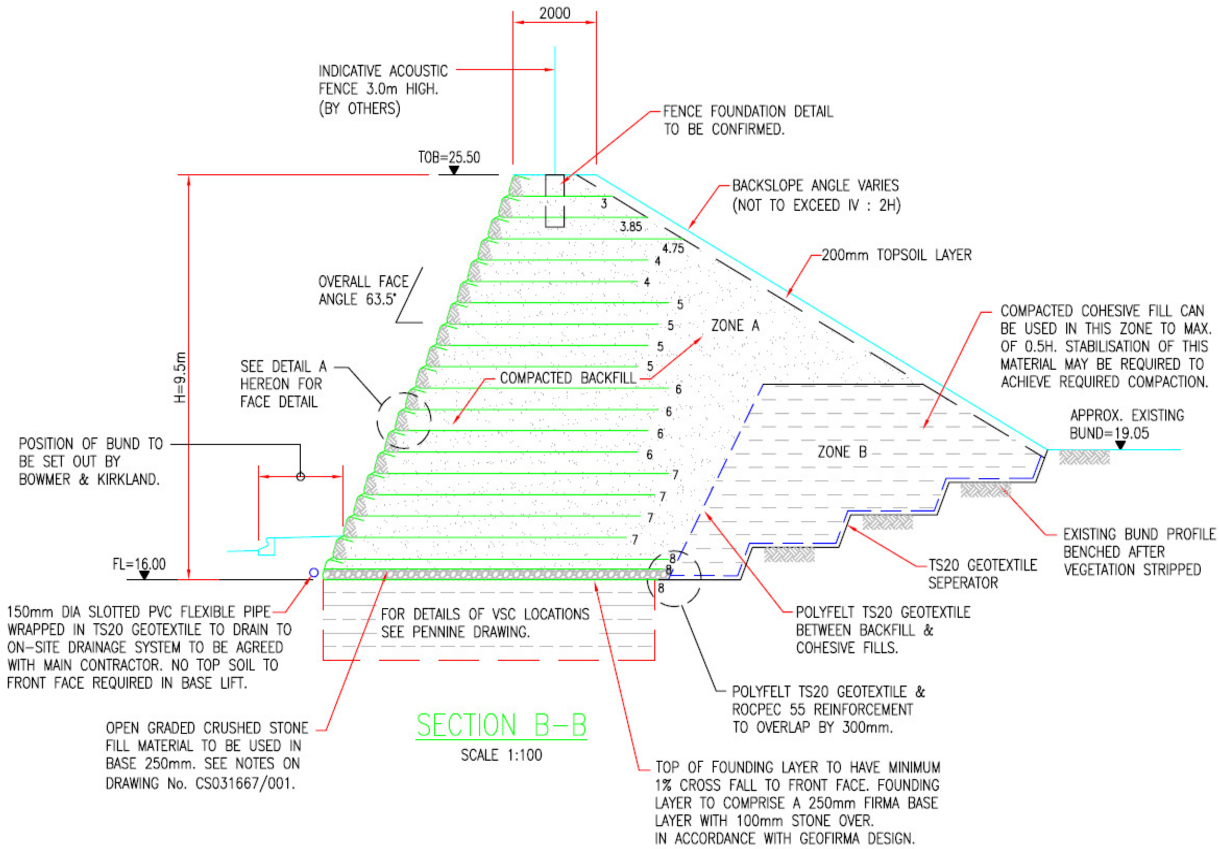
[1] *Information from specialist sub-contractor, PC Construction*

The engineered design specified the use of geo-components in to ensure the stability of the soil bund. The main geo-components were a Rock PEC 55/55 (geocomposite), a Miragrid GX 20/20 (geogrid) and a Polyfelt Green fine mesh. All three were brought to site by road.

Figure 1: Showing typical cross section through the environmental bund constructed at Axis Business Park, Liverpool.



Comparison of the two alternative designs

Environmental and financial costs

Figure 2 illustrates the different approaches required to deliver the two alternative designs, and assigns the calculated values for embodied CO2 to each stage. Figure 3 does the same for the financial costs. The calculations from which the two sets of figures are derived follow.

Figure 2: Flowchart comparing the alternative options for construction of the bund and their associated carbon footprints, (per 50m length).

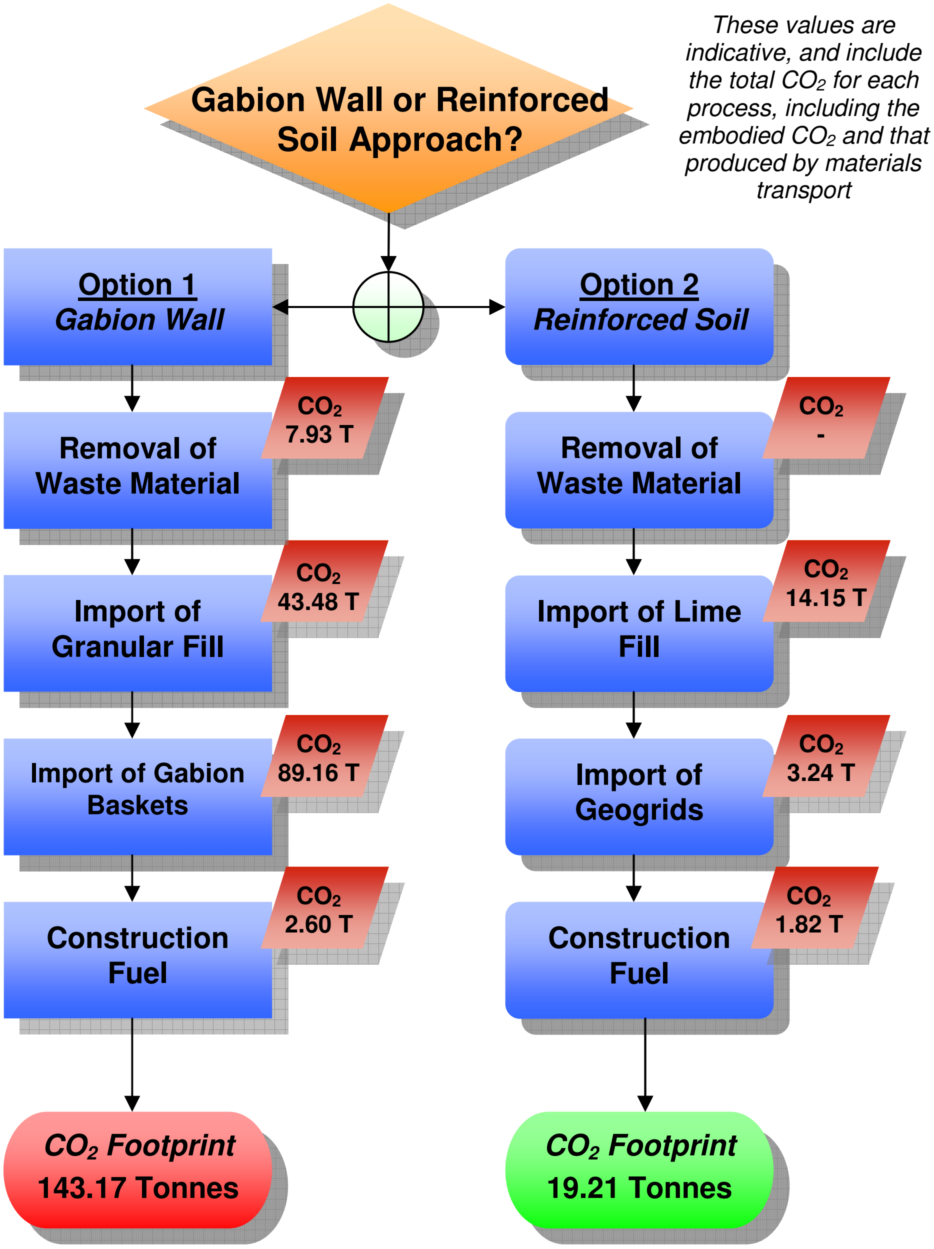
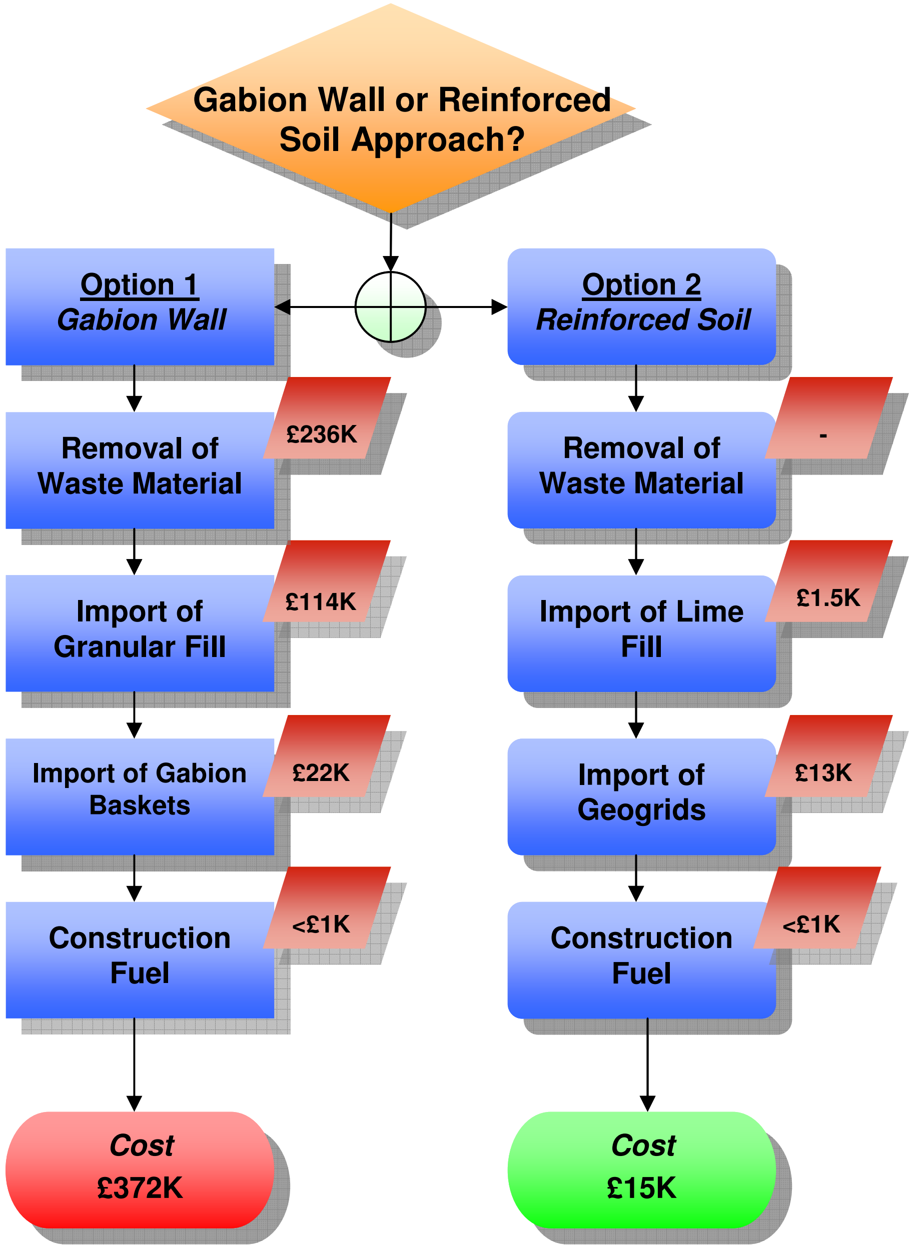


Figure 3: Flowchart comparing the alternative options for construction of the bund and their associated financial costs, (per 50m length).



Supporting calculations

Disposal of waste materials

The CO2 value reflects emissions produced by haulage. The financial cost includes estimates for landfill gate fee, landfill tax and haulage.

Table 1: Carbon & Cost Savings for Waste

Method	Material (Tonnes)	Total $C0_2$[2] (Tonnes)	Total Cost[3] (£)
Gabion Wall	4,000	7.93	236,000
Reinforced Soil	0	0	0
Total Saving	**4,000**	**7.93**	**236,000**

Imported aggregates and lime

The proposed 5,980 tonnes of virgin granular fill required in the original design (gabion stone and drainage) would have a total of 29.90 tonnes of embodied $CO_{2,}$ considering the energy involved in the excavation and processing of the quarried material. Additionally, transport of the granular fill materials by road would have resulted in a further 13.68 tonnes of CO_2 emissions. By contrast, the lime used in the reinforced soil approach resulted in some 13.88 tonnes of embodied CO_2 with only 0.27 tonnes of CO_2 related to the reduced road transportation requirements.

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[2] *Values for CO_2 include embodied energy and that produced by haulage*
[3] *Includes costs for gate fee, tax & haulage*

Table 2: Carbon & Cost Savings for Aggregate Imports

Method	Material (Tonnes)	Total $C0_2$ [4] (Tonnes)	Total Cost (£)
Gabion Wall	5,980	43.58	113,620
Reinforced Soil	18.75	14.15	1,575
Total Saving	**5,961.25**	**29.43**	**112,045**

Geo-components

The original scheme design indicated the use of gabion baskets which needed to be manufactured and delivered to site. The detailed figures in Table 5 show that the embodied CO2 for the gabion baskets is higher than the equivalent figure for the geo-components employed, largely because of the amount of steel involved. (It should be noted that in this case study we are comparing Geosystems with each other, and when Gabions are utilised against more traditional retaining structures they too can offer substantial environmental and financial benefits).

Each 50m of bund required 5,750m2 of Rock PEC 55/55 (with an embodied CO2 content of 0.774 kg CO2 per m², around 4.45 tonnes in total), 1,750m2 of Miragrid GX 20/20 (with an embodied CO2 content of 0.32 kg CO2 per m², around 0.57 tonnes in total), and 1,350m2 of Polyfelt Green (with an embodied CO2 content of just over 0.19 kg CO2 per m², around 0.26 tonnes in total). An additional 0.82 tonnes of CO2 was attributed to the transportation of the geo-components to site. By contrast, the gabion baskets originally proposed would have had a total embodied CO2 content of approximately 88.79 tonnes with an additional 0.37 tonnes being produced during transportation.

[4] *Values for CO_2 include embodied energy and that produced by haulage*

Table 3: Costs and CO_2 associated with the Geosystem

Element	Material (m^2)	Total CO_2 (Tonnes)	Total Cost (£)
Traditional	6,062.5	89.16	22,000
Geosystem	8,850.0	6.09	13,450
Total Saving	**-2,787.5**	**83.07**	**8,550**

Site works

Due to the additional materials handling associated with indicative Gabion design, approximately 2.6 tonnes of CO2 would have been produced from fuel use on site, costing around £370. By contrast the reinforced soil approach would have produced approximately 1.82 tonnes of CO2 and cost around £260.

Table 4: Costs and CO2 for construction fuel

Element	Total CO_2 (Tonnes)	Total Cost (£)
Gabion Wall	2.60	370
Reinforced Soil	1.82	260
Total Saving	**0.78**	**110**

Summary

Figures 2 and 3 (above) provide summaries of the total embodied CO2 (carbon footprint) including transport, and the financial cost for both solutions (the gabion wall design and the reinforced soil bund).

Basis for carbon and cost calculations

Table 5 provides the basis for the embodied CO2 calculations used in this Case Study. This excludes any consideration of CO2 emissions from transport to site or the CO2 associated with the formation of the Geomaterials.

Table 5: Calculations used to determine the embodied CO_2 of materials

Product	Material (and % by weight)	Mass (tonnes)	Embodied Carbon Value[5] in tonnes of CO_2 per tonne of material		Embodied Carbon (tonnes)
Gabion Mesh (PVC)	Steel (80.9)	12.94	Steel Wire (Virgin)	2.83	88.79
	Zinc (10.0)		Zinc (Virgin)	3.86	
	Aluminium (0.5)		Aluminium (Virgin)	11.46	
	PVC (8.6)		PVC (General)	2.41	
Gabion Fill	Aggregate	1,980	Aggregate	0.005	9.90
Granular Backfill	Aggregate	4,000	Aggregate	0.005	20.00
Rock PEC 55/55	Poly-propylene (50.0)	2.07	Polypropylene	2.7	4.45
	Polyester (50.0)		General Polyethylene	1.6	
Miragrid GX 20/20	Polyester	0.36	General Polyethylene	1.6	0.57
Polyfelt Green B110	Fibreglass	0.17	Fibreglass	1.53	0.26
Lime	Lime	18.75	Lime (General)	0.74	13.88

[5] *University of Bath & Carbon Trust, Inventory of Carbon & Energy Version 1.6a*

Table 6 provides the cost factors used in this Case Study.

Table 5: Material Costs for the Original and Chosen methods and the Source for Costs

Material	Unit price	Source of price
Gabions (PVC coated)	£20.00 / m²	Supplier /Manufacturer
Rock PEC 55/55	£1.80 / m²	Supplier /Manufacturer
Miragrid GX 20/20	£1.00 / m²	Supplier /Manufacturer
Polyfelt Green B110	£1.00 / m2	Supplier /Manufacturer
Granular Fill, (Gabion baskets & drainage fill)	£19.00 / tonne	Specialist Sub-Contractor
Lime	£84.00 / tonne	Contractor
Plant Fuel	£0.38 / litre	Red Diesel Price Tracker (2007)
Landfill Tax & Gate Fee	£45.00 / tonne	WRAP (Comparing the cost of alternative waste treatment options)
Landfill Haulage	£225.00 / 20-tonne load £55.00 / driver / hour	Haulage Company

Conclusions

The Axis Business Park Environmental Bund demonstrates the advantages of selecting an appropriate Geosystem to make use of existing on-site materials. In this project, the use of low specification site-won material was achieved by improving it and integrating it with geo-components in an engineered geosystem. The alternative to re-using this site-won material would have been to dispose of it, and to import higher specification materials instead. These advantages are clear in terms of the savings in cost, carbon and waste.

- The re-use of the site-won material avoided the off-site disposal of 4,000 tonnes of material, equating to a saving of £236,000 in haulage costs, landfill tax and gate costs.
- The chosen Geosystems design eliminated the need to import large volumes of granular fill material, leading to a saving of £112,045.
- Overall, the chosen Geosystems resulted in savings of around 89% in embodied CO2 and 96% in cost terms.

Carbon Footprint

- The reinforced soil Geosystems approach reduced the carbon footprint of this environmental bund by 89% through the utilisation of the site-won material, compared to the original scheme proposal which required imported material, and export of excess waste materials.

- The solution saved approximately 154 tonnes of CO_2, equivalent to more than 26 round trips from London to Amsterdam by plane[6]. By way of comparison, it would be necessary to plant approximately 220 ash trees[7] to offset this.

[6] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[7] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

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Material change for a better environment

Sustainable Geosystems in Civil Engineering Applications

Commonhead Junction Improvement, Swindon

(Photograph courtesy of Carillion Construction PLC)

At Commonhead Junction, Swindon the re-use of site-won materials and locally imported clay within an engineered Geosystem, (incorporating a geogrid geo-component), resulted in substantial financial and environmental savings in the earthworks package over the original design.

Commonhead Junction Case Study

The Commonhead Junction improvement involved the construction of a dual two-lane flyover at the Commonhead Roundabout on the A417 / A419, to the southeast of Swindon. The work was commissioned by the Highways Agency, with Mouchel Parkman as scheme designer and Alfred M^c^Alpine (now Carillion plc) as main contractor.

Key facts

The use of a geogrid allowed cohesive fill to be used instead of primary aggregate, and at a steeper angle than would normally be the case with clays.

This enabled 35,388 tonnes of site-won Gault Clay to be re-used on site, reducing the volume of material disposed /used off site.

In addition, 46,386 tonnes of locally available surplus Oxford Clay from a nearby landfill site were used for the project.

The availability and use of site-won Gault Clay and locally imported Oxford Clay in this Geosystem meant that the import by rail and road of 81,774 tonnes of a higher specification granular fill was unnecessary.

Project details

The original scheme proposal involved importing granular fill to construct the approach embankments to the proposed flyover within the central reservation of the existing dual carriageway. The use of granular fill was specified to enable the embankment side slopes to be constructed at a sufficiently steep angle to ensure the footprint did not spread beyond the available space.

Alfred McAlpine determined that this granular fill would be sourced from Frome, Somerset, and delivered to site by rail and then road for the construction of the approach embankments.

Instead, by using a Geogrid to reinforce the site-won Gault Clay, the volume of excess site material requiring disposal as originally planned was greatly reduced. Additionally, surplus Oxford Clay from the excavation of cells at Purton Landfill was also utilised, thereby further reducing the import of granular fill from Frome. The geogrid reinforcement ensured that the embankment slopes met the necessary 1:2 slope profile which would have been achieved by the unreinforced granular material. All of the clay was compacted, and reinforced, to meet the Highways Agency's specifications.

Comparison of the two designs

Environmental and financial costs

Figure 1 illustrates the different approaches required to deliver the two alternative designs, and assigns the calculated values for embodied CO_2 to each stage. Figure 2 does the same for the financial costs. The calculations from which the two sets of figures are derived follow.

Figure 1: Flowchart comparing the alternative options for construction of the embankment and their associated carbon footprints

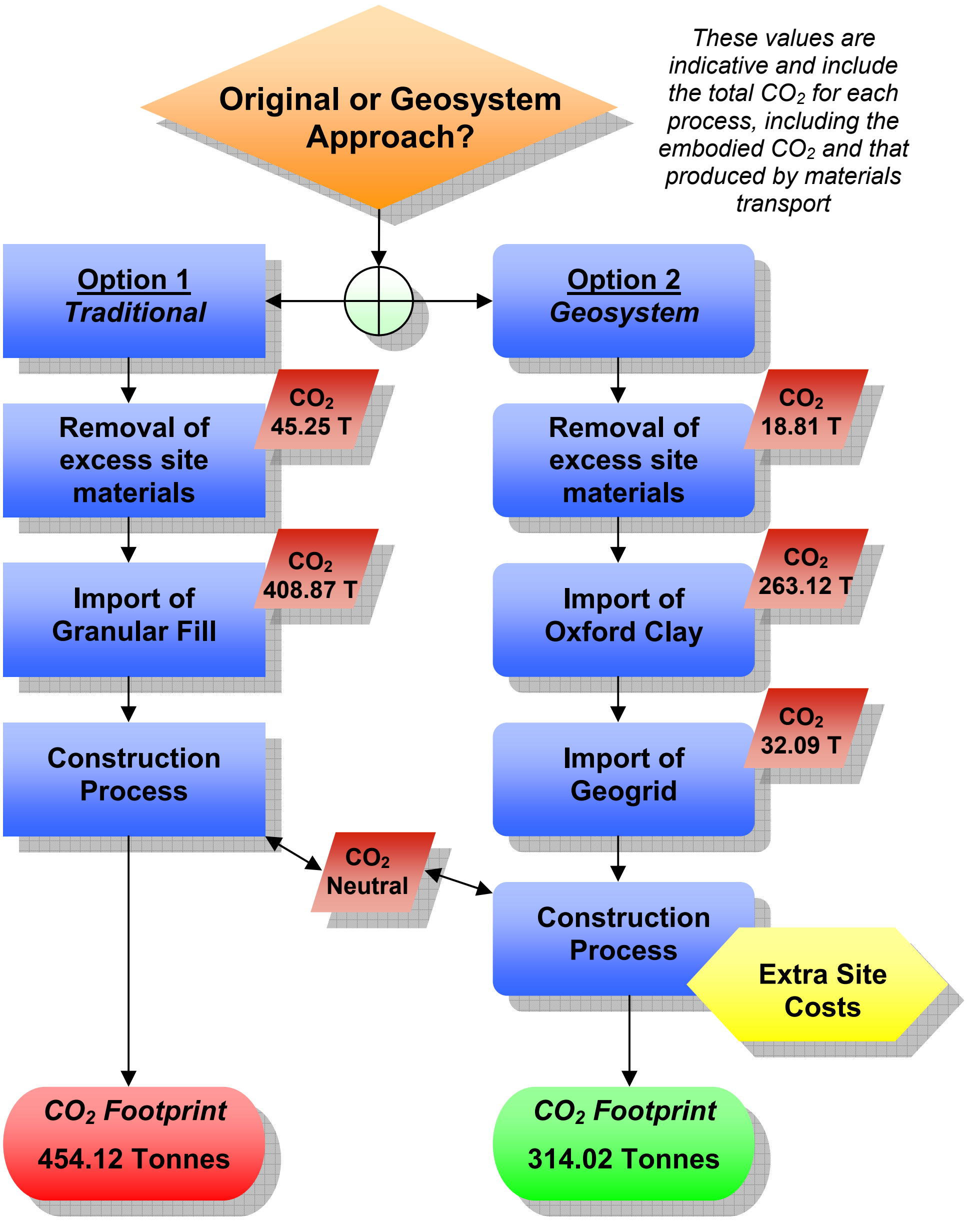
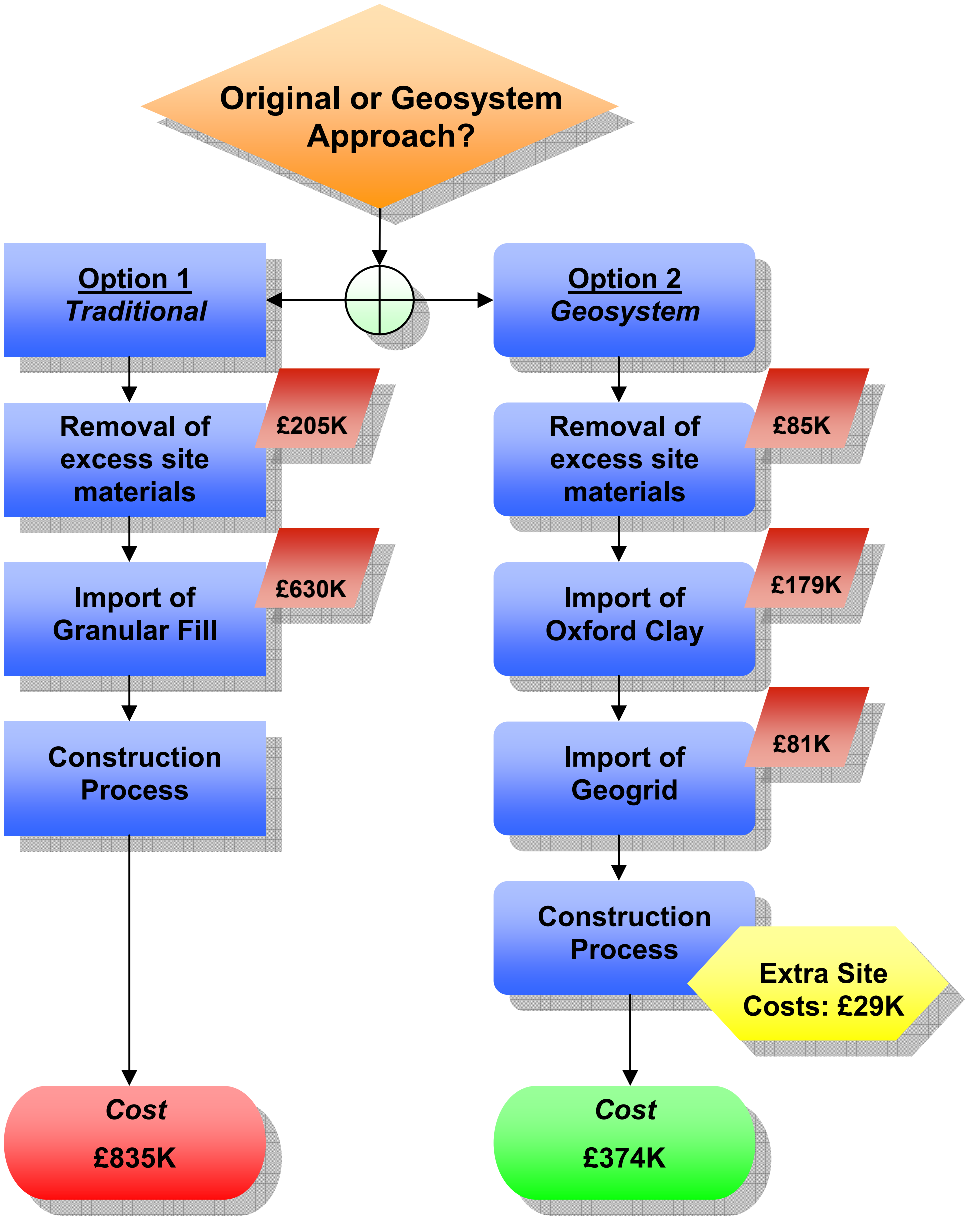


Figure 2: Flowchart comparing the alternative options for construction of the embankment and their associated financial costs



Supporting calculations

Disposal of waste materials

The original design proposals included the removal of around 60,564 tonnes of Gault Clay arising from the approach embankments construction works. This material was deemed unsuitable for the creation of the embankment side slopes at the desired slope angles. The material was therefore to be transported via road and deposited at Hill's Quarry in South Cerney, some 5 miles north of the site.

However, using a Geosystem which incorporated geo-component in the form of a geogrid, 35,388 tonnes of Gault Clay were re-used on-site leaving 25,176 tonnes to be transported to Hill's Quarry where the clay was used in the quarry restoration scheme. The ability of the quarry to make use of this quantity of material resulted in a significantly reduced cost of disposal of the material, estimated at £85,346.

The reduction in the volume of waste in turn significantly reduced the carbon footprint by more than halving the volume of material to be transported to Hill's Quarry. Transporting 60,564 tonnes of waste material to the disposal site, as proposed in the original scheme, would have resulted in approximately 45.25 tonnes of CO_2. By contrast, due to the reduced volume of waste materials as a consequence of using the Geosystems approach, only 18.81 tonnes of CO_2 were produced: a saving of around 58% for this element of the project.

Table 1: Comparison of Exported Waste Materials

Method	Material[1] (Tonnes)	Total $C0_2$[2] (Tonnes)	Total Cost[1] (£)
Traditional	60,564	45.25	205,311
Geosystem	25,176	18.81	85,346
Total Saving	**35,388**	**26.44**	**119,965**

Import of Fill Materials

The original embankment design required the import of 81,774 tonnes of granular fill from Frome. This would have involved an initial rail journey from the quarry to Wootton Basset rail depot, a distance of approximately 38 miles, and then approximately 9 miles by road to the Commonhead site. The estimated contractor cost of this was £629,660.

Using a Geosystem solution meant that site-won Gault Clay and locally imported Oxford Clay could be used instead of the granular fill. In all, 35,388 tonnes of site-won Gault Clay were re-used, and 46,386 tonnes of Oxford Clay were imported from Purton Landfill, approximately 4.5 miles from the site. Bringing the Oxford Clay to site incurred a cost of around £179,280, yielding a saving of £450,380.

The greatly reduced volume of granular material required, coupled with the close proximity of the source of the Oxford Clay, resulted in a significantly reduced carbon footprint. The 81,774 tonnes of granular fill originally proposed would have brought with them a carbon footprint of just over 520 tonnes (408.87 tonnes of embodied CO_2 from the extraction and processing of the quarried material, plus 112.41 tonnes from transport). By comparison, the

[1] *Provided by the contractor who carried out the site works*
[2] *Values for CO_2 include embodied energy and that produced by haulage*

locally-sourced Oxford Clay was calculated to contribute 231.93 tonnes of embodied CO_2, with an additional 31.19 tonnes of CO_2 generated during its transport. The saving attributable to the Geosystems solution is equivalent to a saving of just under half.

Table 2: Comparison of Imported Fill Materials

Method	Material[3] (Tonnes)	Total $C0_2$ [4] (Tonnes)	Total Cost[3] (£)
Traditional	81,774	521.28	629,660
Geosystem	46,386	263.12	179,280
Total Saving	**35,388**	**258.16**	**450,380**

Geo-component

To ensure the stability of the embankment side slopes at the desired face angles, a geogrid was incorporated into the design, allowing the original 1:2 slope profile to be maintained.

The geogrid was delivered[5] to site by road, with a delivered cost of around £80,666. However its incorporation into the embankments resulted in additional costs in the form of increased site control and supervision requirements at a cost of approximately £29,440. A total of approximately 15.76 tonnes of Fortrac Geogrid was delivered to the site with an embodied CO_2 content of approximately 30.56 tonnes. An additional 1.53 tonnes of CO_2 was estimated to be released through the transportation of the geogrid to site.

[3] *Value provided by the contractor who carried out the site works*
[4] *Values for CO_2 include embodied energy and that produced by haulage*
[5] *The Fortrac Geogrid was delivered from Trafford Park, Manchester Depot*

Table 3: Costs and CO_2 associated with the Geo-component

Element	Material[6] (Tonnes)	Total CO_2[7] (Tonnes)	Total Cost[6] (£)
Geo-component	15.76	32.09	80,666
Additional Site Control	-	-	29,440
Total	**15.76**	**32.09**	**110,106**

Summary

Figures 1 and 2 (above) provide summaries of the total embodied CO_2 (carbon footprint) including transport, and the financial cost for both solutions (the traditional aggregate-based embankment and the Geosystem-based reinforced soil structure).

Basis for carbon and cost calculations

Table 4 provides the basis for the embodied CO_2 calculations used in this Case Study. This excludes any consideration of CO_2 emissions from transport to site or CO_2 produced during the manufacture of the Geomaterials.

Table 4: Calculations used to determine the embodied CO_2 of materials

Supplier	Product	Mass (tonnes)	Embodied Carbon Value[8] in tonnes of CO_2 per tonne of material		Embodied Carbon (tonnes)
Frome Quarry	Aggregate	81,770	Aggregate	0.005	408.87
Purton Landfill	Aggregate	46,390	Aggregate	0.005	231.93
Huesker Ltd.	Fortrac 35/20-20	15.77	Polyester	1.94	30.56

[6] Costs provided by the contractor who carried out the site works
[7] Values for CO_2 include embodied energy and that produced by haulage
[8] University of Bath & Carbon Trust, Inventory of Carbon & Energy Version 1.6a

Table 5 provides the cost factors used in this Case Study.

Table 5: Material Costs for the Original and Chosen methods and the Source for Costs

Material	Unit price	Source of price
Landfill haulage and gate fee	£3.39 / tonne	Main contractor
Importing fill (Oxford Clay)	£3.90 / tonne	Main contractor
Importing Fill (Granular)	£7.70 / tonne	Main contractor
Fortrac Geogrid 35/20-20	£1.28 / m^2	Main contractor
Additional engineers	£500 to cover 250m^3/day clay fill placement	Main contractor
	£120 to cover 8 hrs / day for labour	Main contractor
	£60 / day for surveying (2 hrs)	Main contractor
	£0.72 / m^3 fill placement	Main contractor

Conclusions

The construction of the embankments for the Commonhead Junction Improvements illustrates the advantages of using an engineered Geosystem with a geo-component which allows a lower specification site-won material to be used in construction, as an alternative to the use of granular fill. It also serves to illustrate the inherent CO_2 and cost saving available from the efficient use of locally available materials.

- The Geosystems approach resulted in 30% lower CO_2 emissions compared to the traditional design for this element of the project, and a cost saving of over 50%.
- These gains were contributed by a combination of re-use of site-won Gault Clay (with associated savings in transport to landfill), and the import of surplus local Oxford Clay instead of virgin aggregate.
- The reduction in waste generation also produced a cost saving of £119,965 from reduced disposal costs.
- No need to import granular fill material for the embankment resulted in a cost saving of £450,380.

Carbon Footprint

- The Geosystems approach reduced the carbon footprint of the construction of the embankments on this project by 30% through utilising lower specification site-won material combined with an engineered geo-component in the form of a geogrid, when compared with the original proposal which specified the use of imported granular material.

- The solution saved approximately 140 tonnes of CO_2, equivalent to six round trips from London to Berlin by plane [(9)]. By way of comparison, it would be necessary to plant approximately 200 ash trees [(10)] to offset this.

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[9] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[10] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

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Conclusions

The use of a Geosystems solution (in the form of a crib wall in place of the more traditional solution of a reinforced concrete retaining wall) at the boundary of No1 Vale Road and the A321 demonstrates the cost, logistical and environmental benefits which can be realised.

- Through the reduction of excavated waste arising from the project, a reduction in the associated CO_2 footprint of more than 70% was achieved.
- The reduction in waste material also meant a saving of £12,678 from reduced transportation, landfill tax and gate fee costs.
- The reduction in excavated waste reduced the need for imported fill at a cost saving of around 63%.
- Overall the reduction in costs achieved through the adoption of the alternative solution was £20,900.

Carbon Footprint

- The Geosystems solution reduced the associated carbon footprint of this retaining structure by more than 70% through a reduction in the quantity of excavation and the incorporation of a more efficient crib wall geo-component, compared to the originally proposed reinforced concrete wall solution.

- The Geosystem solution saved approximately 23 tonnes of CO_2, equivalent to more than four round trips from London to Paris by plane[8]. By way of comparison, it would be necessary to plant approximately 36 ash trees[9] to offset this.

[8] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[9] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

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Material change for a better environment

Crib Wall, Ash Vale, Aldershot

(Photograph courtesy of Phi Group Ltd (a Keller Group Company))

A partially collapsed and dilapidated 20m section of brick retaining wall along the boundary with the A321 (Vale Road) was replaced during highway and bridge upgrades and improvements. The use of a Concrete Crib Wall in the design solution resulted in a CO_2 reduction of 70%.

Ash Vale Crib Wall Case Study

A dilapidated 20m brick retaining wall was present along the bottom of the garden at No. 1 Vale Road, adjacent to the A321 Vale Road embankment. Surrey County Council replaced this wall as part of a scheduled programme of upgrades and improvements to the A321. The work was commissioned by Surrey County Council, and Osbourne Ltd was the Main Contractor with Phi Keller providing specialist design and construction of the Crib Wall.

Key facts

The use of a crib wall over a traditional "L" shaped reinforced concrete retaining wall saved 220 tonnes of waste material which would otherwise have been sent to landfill for disposal.

Keeping the material on site avoided the need to import 220 tonnes of granular fill.

Overall, the reduction in waste and import by selection of the Geosystems approach over the reinforced concrete wall meant a CO_2 saving of 70% and a cost saving of around 64%, not including the avoided costs of diverting or re-instating services.

Project details

By using a Geosystems solution, savings were realised during the construction phase through the reduction of both waste material and the amount of imported fill. The original proposal (see Figure 1) involved the excavation of the road embankment to create a wide enough base for the reinforced concrete retaining wall, which was to be clad in brick on the side facing the residential property.

However, the traditional solution was logistically problematical due to the presence of several utilities within the embankment. The crib wall alternative solution (see Figure 2) was proposed, and ultimately implemented, since this required a reduced amount of embankment excavation and left the utilities undisturbed. Additionally the Geosystem solution resulted in less encroachment into the garden of the residential property.

Significantly, by reducing the volume of embankment excavation, the Geosystem solution reduced the amount of waste material generated and correspondingly the need to import granular fill. This produced the reduction in associated cost and CO_2.

Comparison of the two designs

Environmental and financial costs

Figure 3 illustrates the different approaches required to deliver the two alternative designs, and assigns the calculated values for embodied CO_2 to each stage. Figure 4 does the same thing for the financial costs. The calculations from which the two sets of figures are derived follow.

Figure 1: Detail of the originally proposed reinforced concrete wall with brick cladding design.

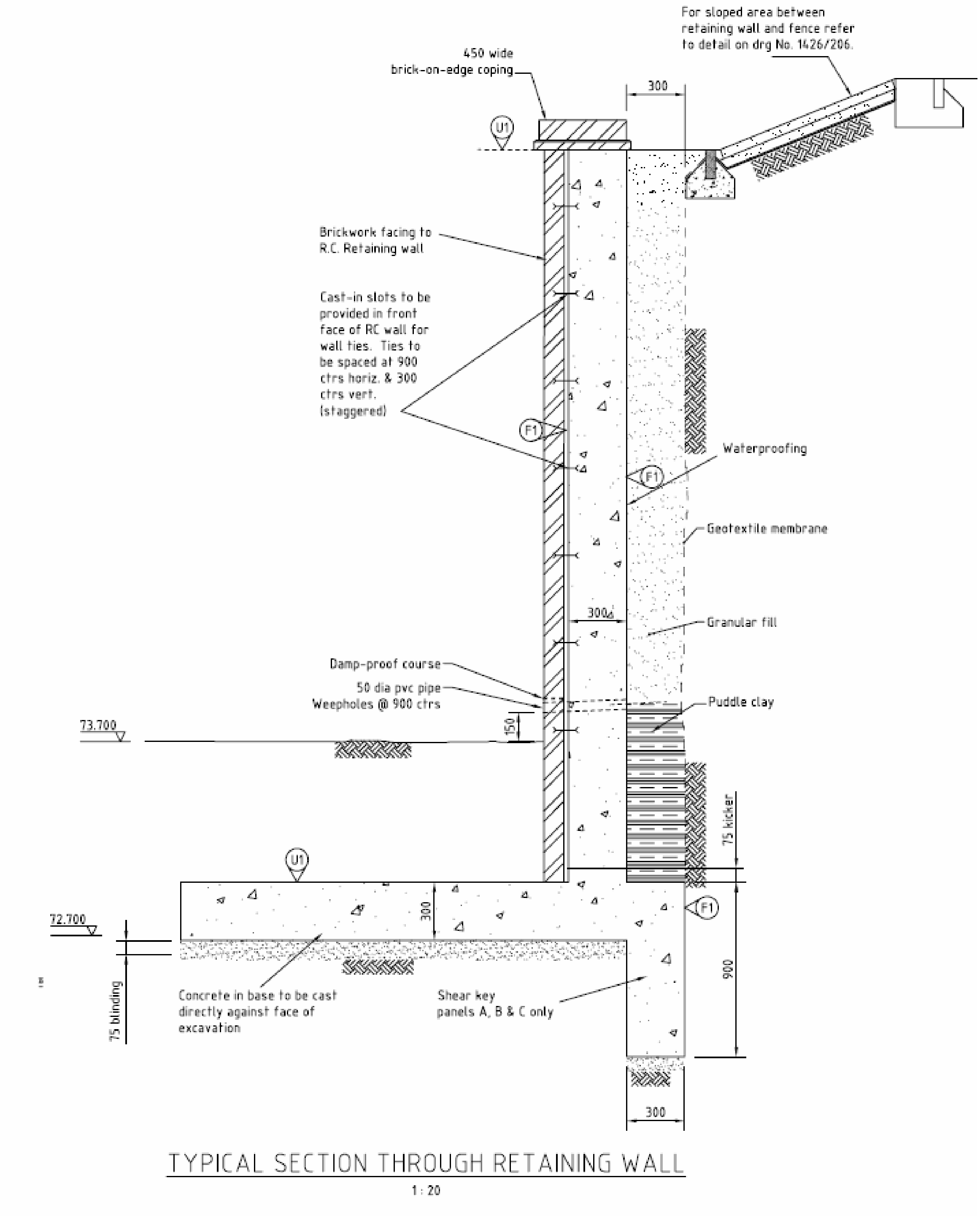


Figure 2: Detail of the Concrete Crib Wall design constructed at Ash Vale, Aldershot

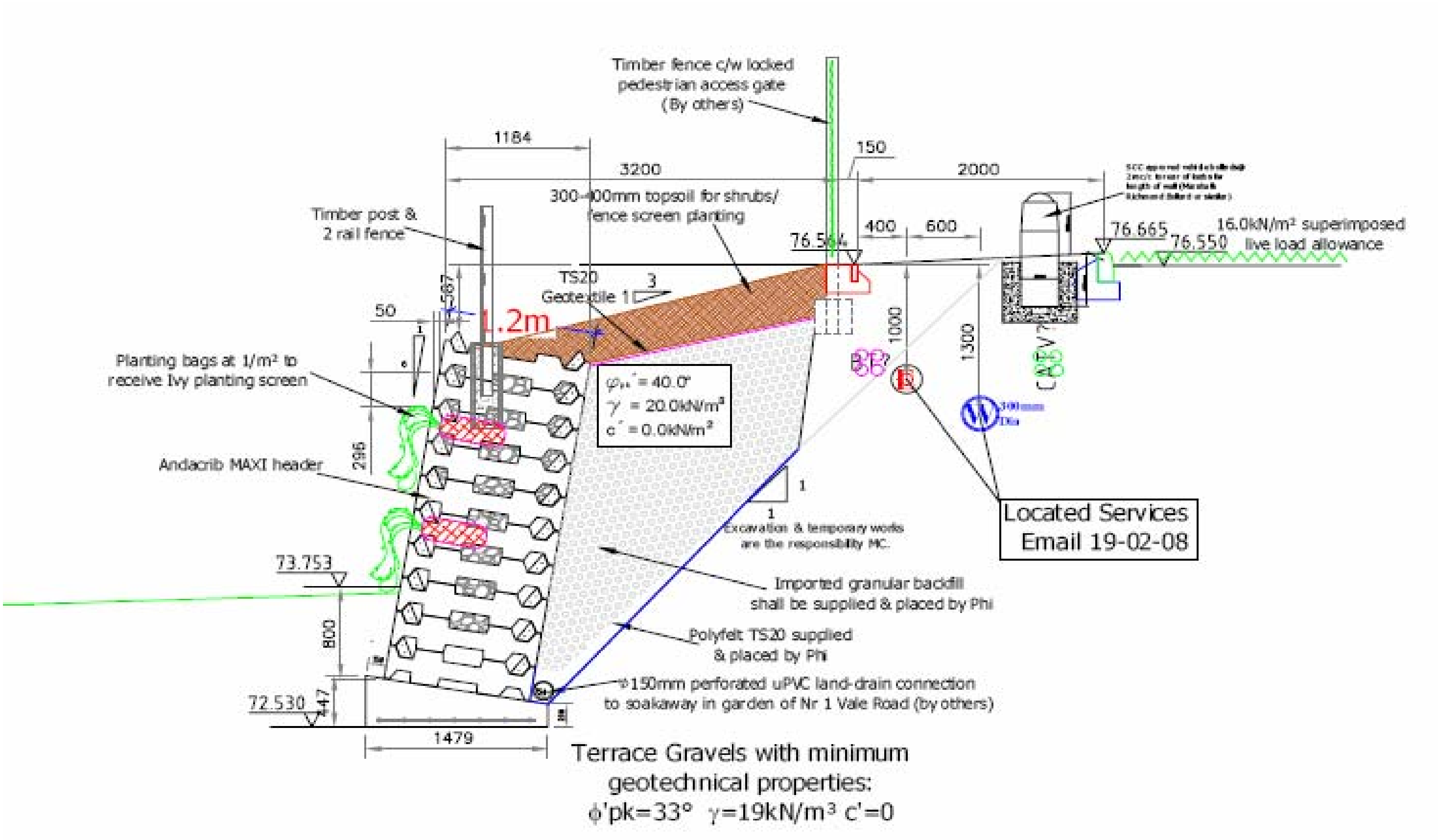


Figure 3: Flowchart comparing the alternative options for construction of the retaining wall and their associated carbon footprints

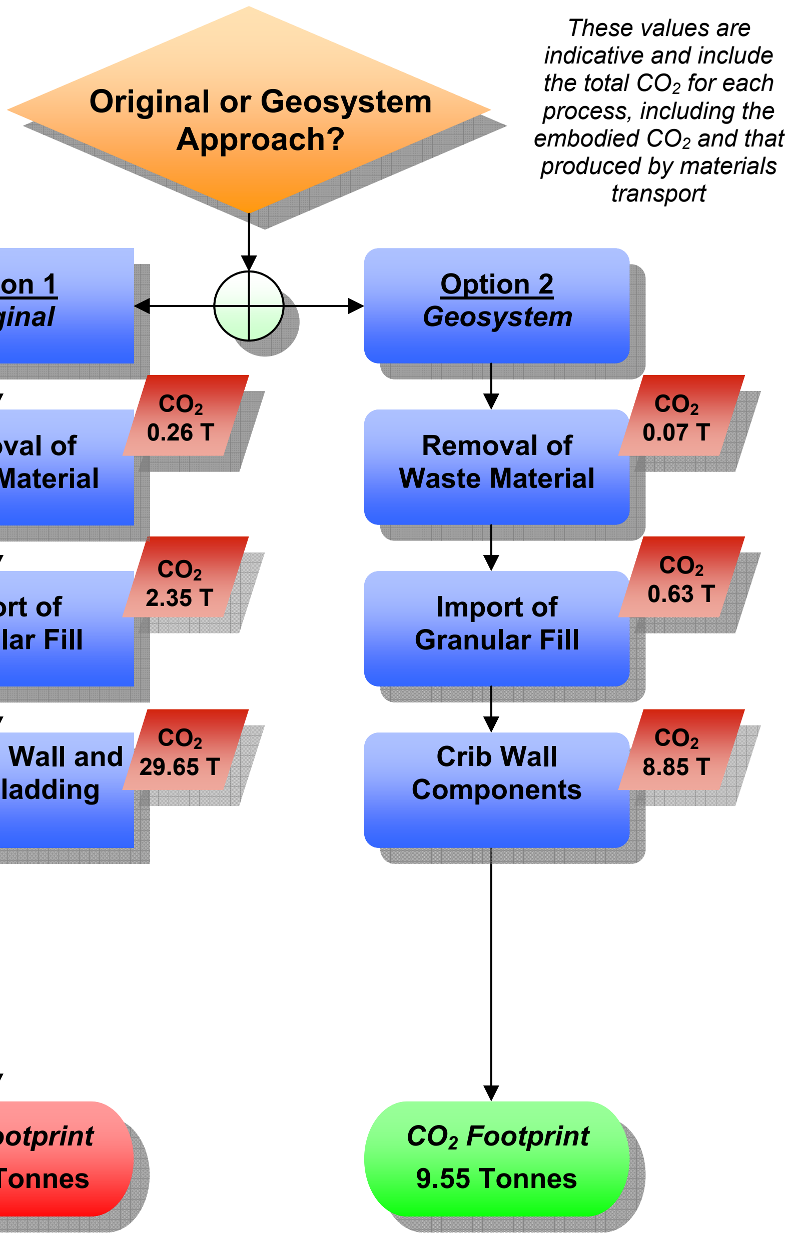
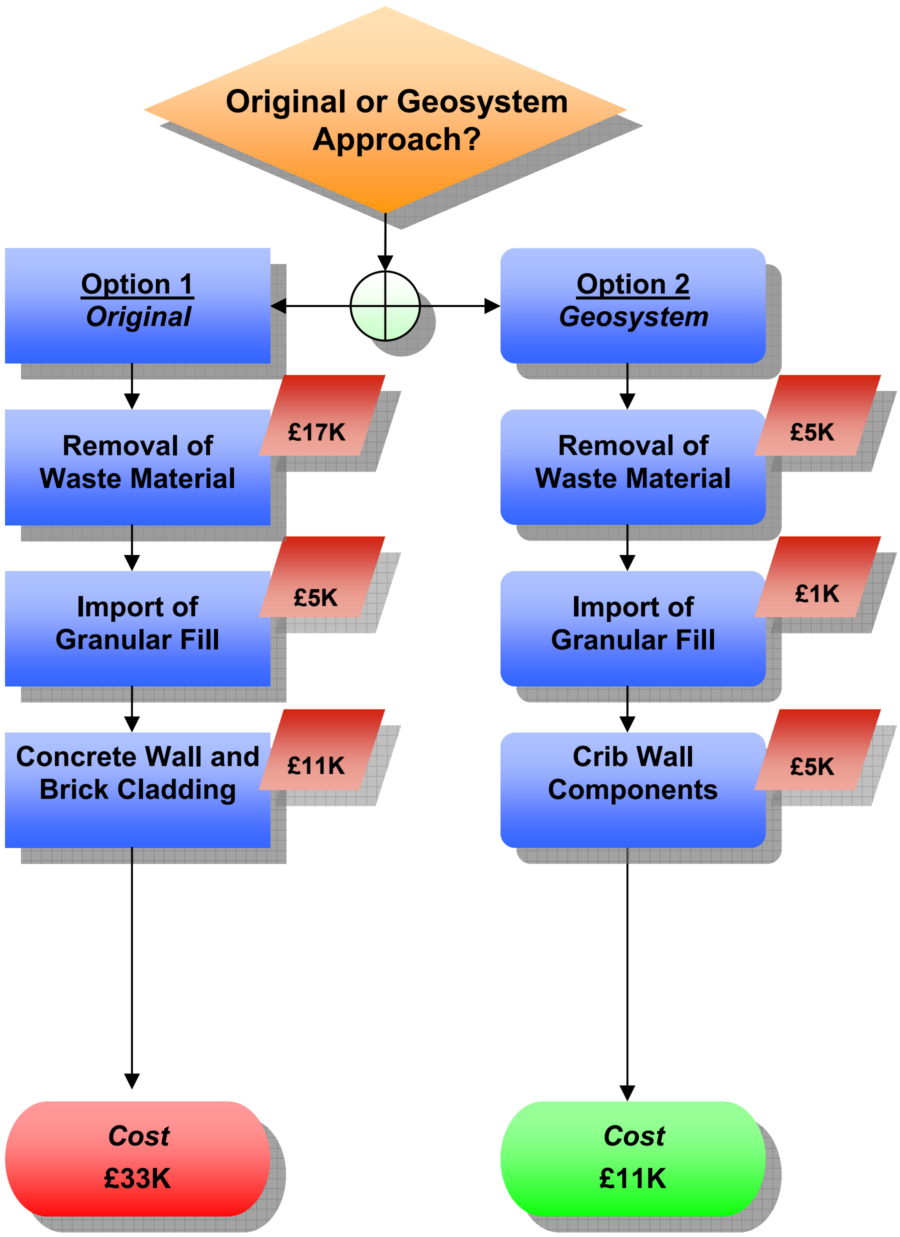


Figure 4: Flowchart comparing the alternative options for construction of the retaining wall and their associated financial costs.



Supporting calculations

Disposal of waste materials

The original proposal would have involved the removal of some 300 tonnes of excess material from the ground works to enable construction of a reinforced concrete retaining wall. This waste material would have been transported by road and disposed of at Runfold North Landfill, 5.75 miles away.

However, the reduced width of the Geosystems solution compared to the reinforced concrete wall solution resulted in only 80 tonnes of waste material being generated from the excavation works. This reduction in excavation quantities resulted in a cost saving of approximately £12,678 from reduced haulage, landfill tax and gate fees for the disposal of the waste material.

This reduction in the volume of waste in turn significantly reduced the carbon footprint of the project. Transporting 300 tonnes of waste material to the disposal site, as proposed in the original scheme, would have resulted in 0.26 tonnes of CO_2. By contrast, the removal of only 80 tonnes of excess material in the Geosystems approach produced only 0.07 tonnes of CO_2, a saving on this element of the project of 73%.

Table 1: Comparison of Exported Waste Materials

Method	Material (Tonnes)	Total CO_2[1] (Tonnes)	Total Cost[2] (£)
Reinforced Concrete Wall	300	0.26	17,290
Concrete Crib Wall	80	0.07	4,610
Total Saving	**220**	**0.19**	**12,680**

Import of Fill Materials

In the original proposal (based on a reinforced concrete retaining wall), 300 tonnes of granular fill would have been required to fill the void behind the concrete retaining wall upstand. This material would have been imported from Mortimer, Berkshire by road, a distance of 19 miles, at a calculated cost of approximately £4,950.

The Geosystems solution meant that less material needed to be removed, and a correspondingly reduced quantity of imported granular fill was needed to construct the crib wall. The reduction of 80 tonnes of imported fill saved around £1,320, and resulted in a significantly reduced carbon footprint.

The 300 tonnes of imported granular fill required by the original solution would have had a total of 1.50 tonnes of embodied CO_2. Additionally, transportation of the imported materials would have generated a further 0.85 tonnes. By contrast, the reduced quantities in the Geosystems solution involved a total of some 0.40 tonnes of embodied CO_2 with an additional 0.23 tonnes of CO_2 generated during delivery.

[1] *Values for CO_2 include embodied energy and that produced by haulage*
[2] *Includes costs for gate fee, tax & haulage*

Table 2: Comparison of Imported Fill Materials

Method	**Material (Tonnes)**	**Total $C0_2$ [3] (Tonnes)**	**Total Cost[4] (£)**
Reinforced Concrete Wall	300	2.35	4,950
Concrete Crib Wall	80	0.67	1,320
Total Saving	**220**	**1.68**	**3,630**

Structural materials

Concrete brick-clad wall

The original design was for a reinforced concrete wall clad with bricks. Around 74 tonnes of concrete would have been necessary to construct the reinforced concrete wall, which would have had an embodied CO_2 content of approximately 17.93 tonnes with an additional 0.05 tonnes of CO_2 released during delivery to site. The concrete would also need to be reinforced with (energy-intensive) steel, which would have contributed an additional 4.95 tonnes of embodied CO_2. Approximately 60m^2 of brick cladding would have been needed to complete the structure, with an embodied CO_2 content of 6.70 tonnes, with a further 0.02 tonnes of CO_2 being released during transportation of the bricks. The reinforced concrete and brick cladding materials would have cost approximately £10,630.

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[3] Values for CO_2 include embodied energy and that produced by haulage
[4] Costings include haulage and were provided by the contractor

Geosystem

The crib wall was constructed using Andacrib reinforced concrete geo-components. The Andacrib components were delivered[5] to site by road resulting in an overall delivered cost of £5,200.

A total of 121 concrete headers and 212 stretchers were delivered, with an embodied CO_2 content of 4.29 tonnes. These were reinforced with steel, adding 0.09 tonnes of embodied CO_2. An estimated 0.76 tonnes of CO_2 was generated through the transportation of the Andacrib components to site.

Slightly less than 30 tonnes of concrete was required for the footer, with an associated embodied CO_2 content of 3.69 tonnes (and an additional 0.02 tonnes of CO_2 arising from its delivery).

Table 3: Costs and CO_2 associated with the structural materials

Element	Total $C0_2$[6] (Tonnes)	Total Cost[6] (£)
Reinforced Concrete Wall	29.77	10,630
Concrete Crib Wall	8.87	5,200
Total Saving	**20.9**	**5,430**

Summary

Figures 3 and 4 (above) provide summaries of the total embodied CO_2 (carbon footprint) including transport, and the financial cost for both solutions (the traditional reinforced concrete wall design and the Geosystem-based crib wall).

5 Assumed that all Andacrib were imported from Nuneaton, Warwickshire
6 Values for CO_2 include embodied energy and that produced by haulage

Basis for carbon and cost calculations

Table 4 provides the basis for the embodied CO_2 calculations used in this Case Study. This excludes any consideration of CO_2 emissions from transport to site or the CO_2 produced during the manufacture of the Geomaterials.

Table 4: Calculations used to determine the embodied CO_2 of materials

Supplier	Product	Mass (tonnes)	Embodied Carbon Value [7] in tonnes of CO_2 per tonne of material		Embodied Carbon (tonnes)
Granular Fill	Aggregate	300	Aggregate	0.005	1.50
Concrete	Concrete	74.4	Concrete (RC40)	0.24	17.86
Rebar	Steel	1.85	Steel (Virgin Rod)	2.68	4.95
Brick Cladding	Facing Bricks Concrete	12.89	Concrete (Facing Bricks)	0.52	6.70
Maxi Header	Concrete	6.68	Concrete (RC35)	0.23	1.54
Rebar	Steel	0.013	Steel (Virgin Rod)	2.68	0.03
Stretcher	Concrete	11.7	Concrete (RC35)	0.23	2.69
Rebar	Steel	0.023	Steel (Virgin Rod)	2.68	0.06
Footing	Concrete	28.8	Concrete (RC20)	0.13	3.74
Granular Fill	Aggregate	80	Aggregate	0.005	0.40

Table 5 provides the cost factors used in this Case Study.

Table 5: Material Costs for the Original and Chosen methods and the Source for Costs

Material	Unit price	Source of price
Waste material (gate fee + tax)	£45 / tonne	WRAP (Comparing the cost of alternative waste treatment options)
Waste material (transport)	£225 / tonne plus £55 / driver-hour	Haulage company
General fill material	£16.50 / tonne	Supplier/manufacturer
Reinforced concrete wall	£297.17 / m length	Supplier/manufacturer
Brick cladding	£79.89 / m²	Supplier/manufacturer
Maxi-header and stretcher	£5,200 (supply deliver build) or £107 / m²	Supplier/manufacturer
Footer concrete	£42 / 1.44 tonnes	Supplier/manufacturer

[7] *University of Bath & Carbon Trust, Inventory of Carbon & Energy Version 1.6a*

Conclusions

The use of a Geosystems solution (in the form of a crib wall in place of the more traditional solution of a reinforced concrete retaining wall) at the boundary of No1 Vale Road and the A321 demonstrates the cost, logistical and environmental benefits which can be realised.

- Through the reduction of excavated waste arising from the project, a reduction in the associated CO_2 footprint of more than 70% was achieved.
- The reduction in waste material also meant a saving of £12,678 from reduced transportation, landfill tax and gate fee costs.
- The reduction in excavated waste reduced the need for imported fill at a cost saving of around 63%.
- Overall the reduction in costs achieved through the adoption of the alternative solution was £20,900.

Carbon Footprint

- The Geosystems solution reduced the associated carbon footprint of this retaining structure by more than 70% through a reduction in the quantity of excavation and the incorporation of a more efficient crib wall geo-component, compared to the originally proposed reinforced concrete wall solution.

- The Geosystem solution saved approximately 23 tonnes of CO_2, equivalent to more than four round trips from London to Paris by plane[8]. By way of comparison, it would be necessary to plant approximately 36 ash trees[9] to offset this.

[8] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[9] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

Waste & Resources
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recycle

Sustainable Geosystems in Civil Engineering Applications

Hunters Lane Household Waste & Recycling Centre, Rugby

(Photograph courtesy of Reinforced Earth Company (part of the Freyssinet Group))

When refurbishing car park retaining walls at the Hunters Lane Household Waste & Recycling Centre, a pre-cast concrete face panel Geosystem with steel strip reinforcement was used in place of a sheet pile wall.

Hunters Land HWRC Case Study

The retaining walls within the car park at Warwickshire County Council's Hunters Lane Household Waste & Recycling Centre (HWRC) were refurbished by contractor Weldon Plant using a concrete face panel and steel strip system designed by the Reinforced Earth Company (RECO). This Geosystem was chosen in place of the more traditional sheet pile wall originally proposed.

Key facts

By using a Geosystem in place of more traditional sheet piling techniques, the risks to nearby structures from associated ground vibrations were minimised.

By using the concrete panel wall system, which combines granular fill and a geo-component in the form of galvanised steel straps attached to the concrete face panels, substantial cost and CO_2 savings were also realised.

Project details

A total of 2,396 tonnes of granular fill were imported to site to construct the retaining walls. The fill was reinforced with zinc galvanised steel strips, and the face was formed from square, pre-cast concrete panels connected to the steel strips. The main advantage of using this method of construction instead of sheet piling was the reduction in risk to the nearby structures from ground vibrations. Additionally, removing the need for steel sheet piles (which bring with them substantial embodied CO_2 from the steel-making process) meant that substantial CO_2 savings could be realised, as well as cost savings.

Traditional design (for comparison)

The sheet piling method would have involved the import of an estimated 112 tonnes of steel sheet piles to provide the main structural elements for the refurbished walls (see Figure 1).

It is not known who would have supplied the piles, so it has been assumed that they would have been delivered from around 50 miles from site (based on the distance to major sheet piling suppliers). The sheet piles themselves would have had an estimated embodied CO_2 content of 315.50 tonnes, with an additional 0.90 tonnes being released during their transport to site. The purchase and delivery of the sheet piles to site would have cost approximately £138,690[1]. It is assumed that no fill would have been required for the works due to the nature of sheet pile installation techniques.

The brick cladding, wall footing and concrete parapet for the sheet pile wall would have been constructed using 244 tonnes of concrete. CEMEX have a local depot in Rugby and it is likely that the material would have been sourced from there. This amount of concrete would have had an embodied CO_2 content of 41.24 tonnes, with an additional 0.03 tonnes of CO_2 being produced through the delivery of the material. The delivered cost of the concrete would have been around £18,550. The parapet would also

[1] *This figure is based upon an indicative rate of £150/m^2 obtained from a piling contractor and is considered to be a conservative estimate.*

have included reinforcement bars, contributing further CO_2 embodied within the steel. However, it is unclear how much reinforcement would have been specified, and so an assessment for this has not been included within the calculations.

The wall was to have been completed with a brick cladding, which it has been assumed would have been sourced from a local merchant. The cladding would have had an estimated embodied CO_2 content of 35.74 tonnes with an additional 0.01 tonnes of CO_2 released during transport. The cost of the brick cladding and the delivery to site would have been around £2,495.

These figures are summarised in Table 1 (after Figures 1 and 2).

Figure 1: Example of original proposed sheet piled wall with brick cladding design

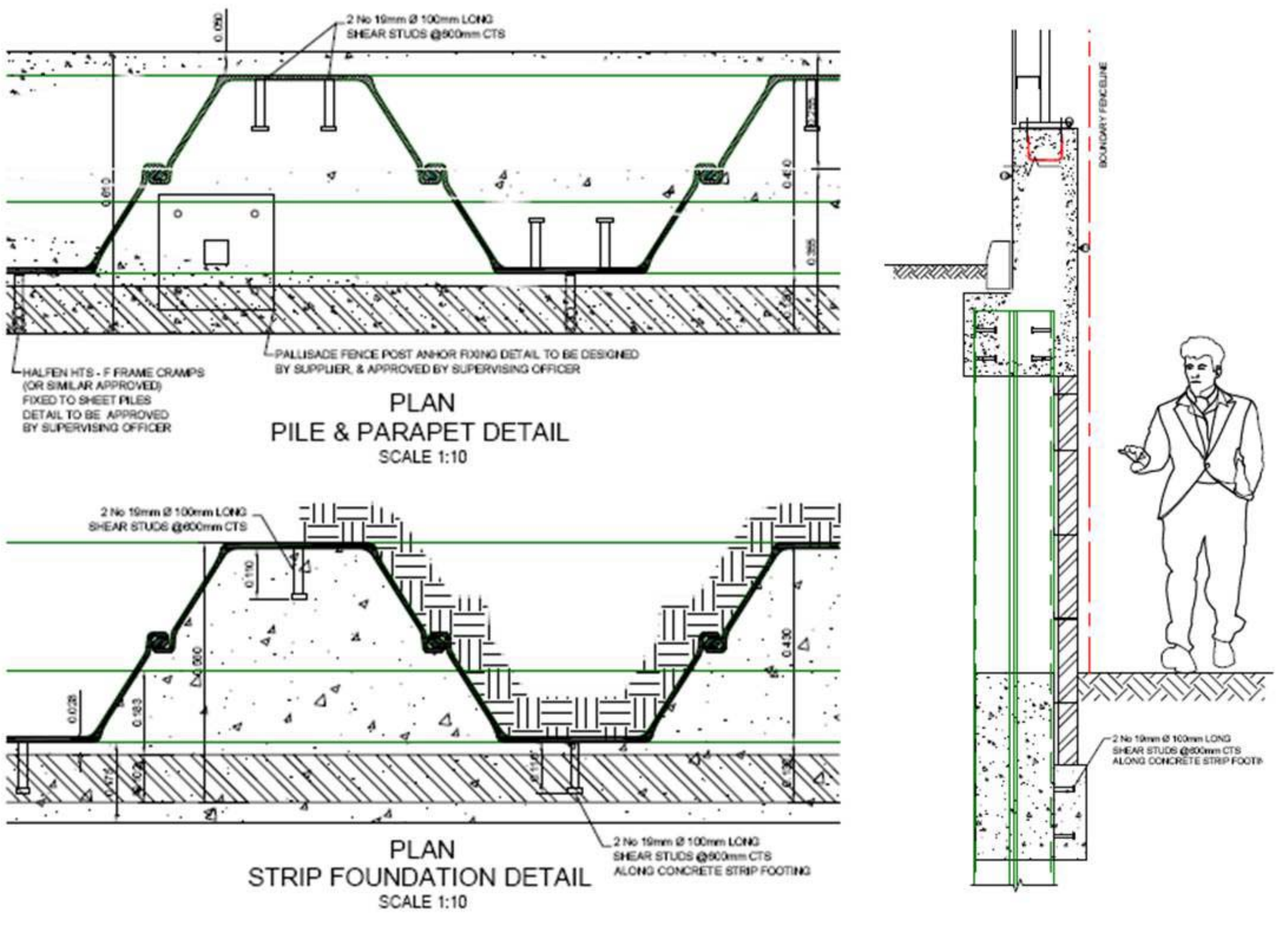
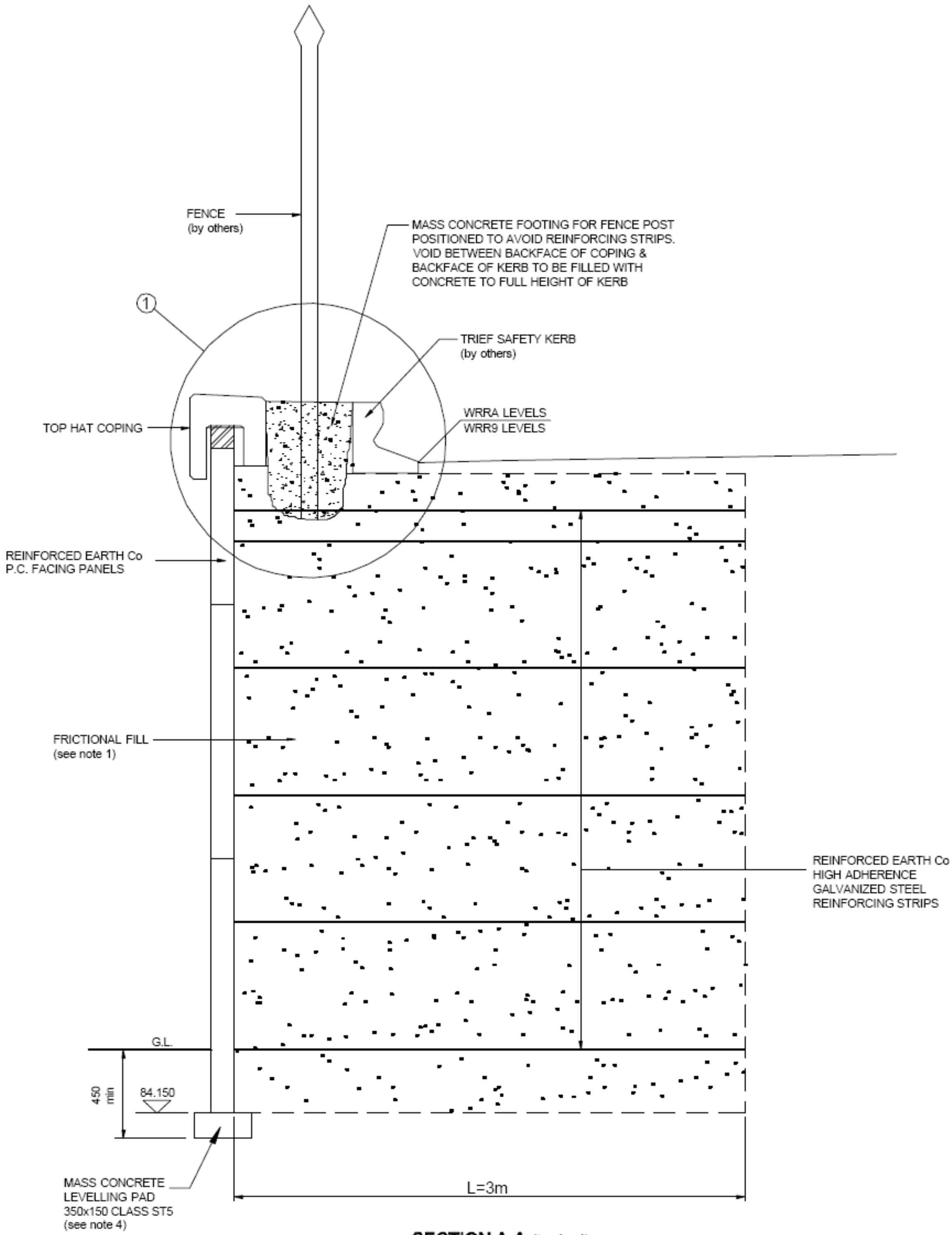


Figure 2: Example of Concrete Panel Wall with steel strips reinforcement used at Hunters Lane



SECTION A-A (typical)
1:25

Table 1: Costs and tonnages of material required for originally proposed **sheet piles**

Material	Material (Tonnes)	Total $C0_2$[2] (Tonnes)	Total Cost[3] (£)
Sheet Piles	112	316.40	138,690
Parapet and Footing Concrete	244	41.27	18,550
Brick Cladding	68	35.75	2,495
Total	**424**	**393.42**	**159,735**

Geosystems design

Using the preferred Geosystems solution to refurbish the car park retaining walls meant that it was necessary to import 2,396 tonnes of high specification granular fill material to site. This was sourced locally, from a supplier approximately 15 miles from site. This material has been assessed as having an embodied CO_2 content of approximately 11.98 tonnes, with an additional 5.38 tonnes of CO_2 being released during transportation of the material to site. The delivered cost of the granular fill was £24,200.

RECO zinc-galvanised steel reinforcement strips were used to stabilise the concrete face panels, being embedded within the fill to provide support for the retaining structure. An estimated 4.60 tonnes of the strips were delivered to site with an embodied CO_2 content of 12.72 tonnes (90% of it from the steel and the rest from the zinc) and an additional 0.41 tonnes of CO_2 attributed to their delivery.

Approximately 170 tonnes of concrete were required for the pre-cast concrete parapet, panel and kerb. This had an embodied CO_2 content of 36.74 tonnes with an additional 3.66 tonnes of CO_2 being produced during transportation to site. The supply of the

[2] *Values for CO_2 include embodied energy and that produced by haulage*
[3] *Provided by the contractor who carried out the site works*

Geosystems geo-components and their delivery to site was at a cost of £51,000 (including pre-cast concrete components).

To complete the Geosystems retaining structure, some 14.74 tonnes of concrete were required, bringing with them an embodied CO_2 content of 1.89 tonnes (with an additional 0.001 tonnes produced during transportation from the nearby CEMEX depot in Rugby). The concrete supply and transportation to site was at a total cost of approximately £466. These figures are summarised in Table 2.

Table 2: Costs and tonnages of material required for Geosystem method of **refurbishment**

Material	Material (Tonnes)	Total $C0_2$ (Tonnes)	Total Cost (£)
Granular Fill	2,396	17.36	24,200
Reinforcing strip	4.6	13.13	51,000
Pre Cast Concrete panels	186	31.97	0[4]
Concrete Footing & Pad	14.74	1.89	466
Total	**2,601.24**	**64.62**	**75,666**

Comparison of the two designs

Construction plant and equipment

Little information is available regarding the construction process and site plant that would have been required for the originally proposed sheet piling method. For the purposes of comparison it has been estimated that the supporting plant would have been similar in cost and CO_2 emissions to that required for the Geosystems solution.

[4] *Included in the £51k total cost of the Reinforcing Strips supplied by RECo*

The CO_2 emissions and financial costs arising from the use of site-based plant and equipment have therefore not been included in this case study.

Environmental and financial costs

Figure 3 illustrates the different approaches required to deliver the two alternative designs, and assigns the calculated values for embodied CO_2 to each stage. Figure 4 does the same thing for the financial costs. The figures are taken from Tables 1 and 2, and further underlying data and calculations are provided in Tables 3 and 4 (which follow Figures 3 and 4).

Figure 3: Flowchart comparing the alternative options for construction of the retaining walls and their associated carbon footprints

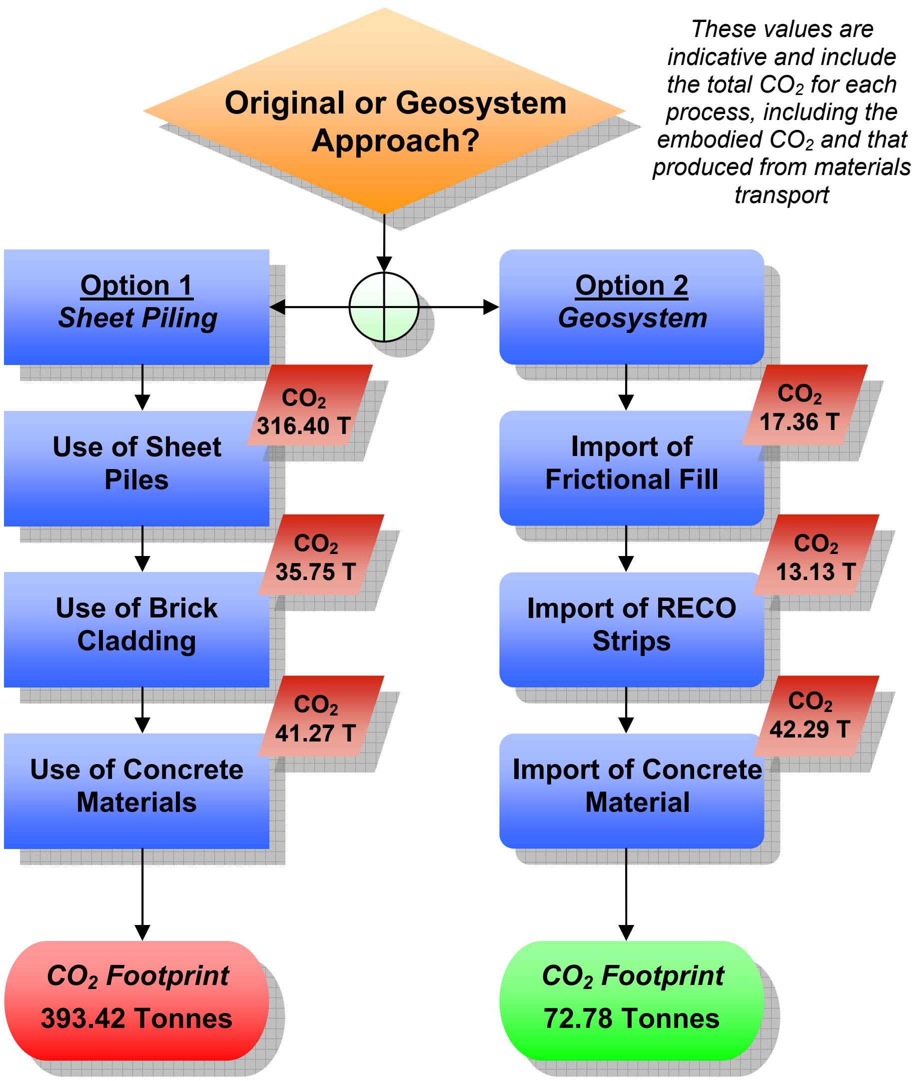
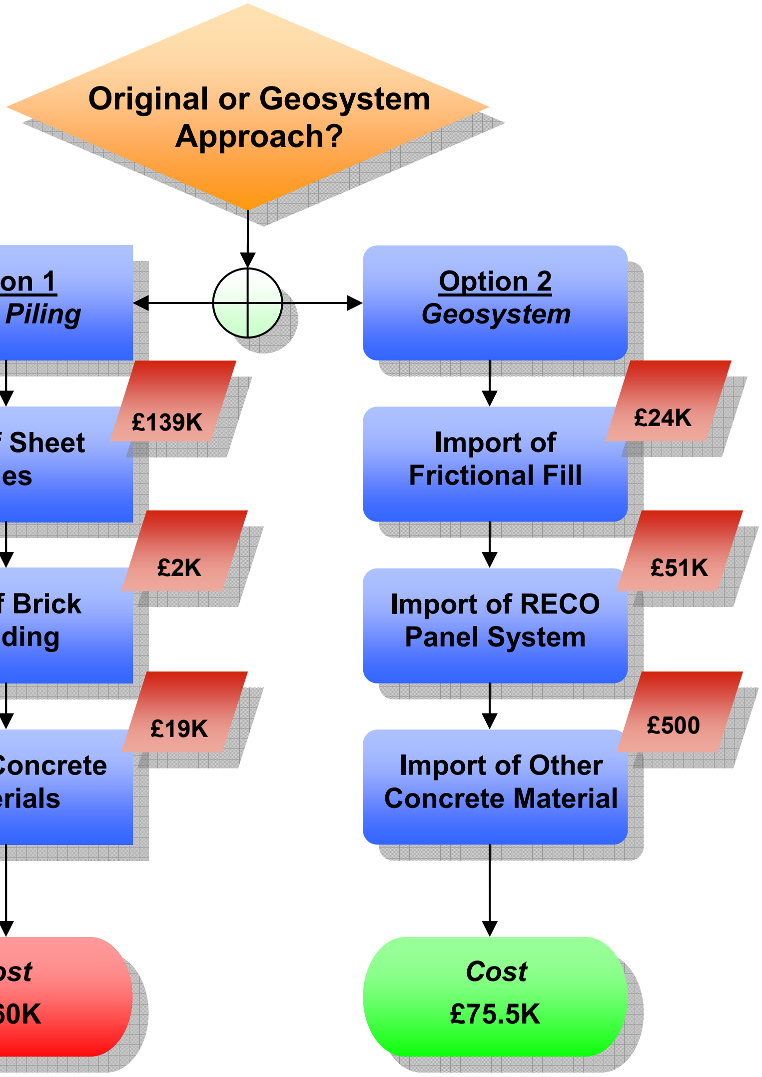


Figure 4: *Flowchart comparing the alternative options for construction of the retaining walls and their associated financial costs*



It should be noted that these values are indicative and some parameters were not included, as outlined in the text above. However, the result of this is considered to produce conservative estimates for the savings of both CO_2 and costs.

Basis for carbon and cost calculations

Table 3 provides the basis for the embodied CO_2 calculations used in this Case Study. This excludes any consideration of CO_2 emissions from transport to site or the CO_2 associated with the manufacture of the Geomaterials.

Table 3: Calculations used to determine the embodied CO_2 of materials

Supplier	Material (and % by weight)	Mass (tonnes)	Embodied Carbon Value [5] in tonnes of CO_2 per tonne of material		Embodied Carbon (tonnes)
RECO Strips	Steel (99)	4.6	Steel sheet (Virgin)	2.51	11.55
	Zinc (1)		Zinc (Virgin)	3.86	
Sheet piles	Steel	11.19	Galvanised steel sheet (Virgin)	2.82	315.50
Brick cladding	Facing bricks	68.73	Facing bricks	0.52	35.74
Footing and pad	Concrete	14.74	Concrete C20	0.128	1.89
Top hat, kerb & panel	Concrete	170.88	Prefabricated Concrete	0.215	36.74
Granular fill	Aggregate	2,395	Aggregate	0.005	11.98

Table 4 provides the cost factors used in this Case Study.

Table 4: Material Costs for the Original and Chosen methods and the Source for Costs

Material	Unit price	Source of price
Sheet piles (delivered)	£150 / m²	Contractor
Ready mix concrete (delivered)	£76 / tonne	Contractor
Granular fill	£10.10 / tonne	Contractor
RECO wall system	£51,000	Contractor / Manufacturer
Facing bricks	£79.89 / m²	SPONS

[5] *University of Bath & Carbon Trust, Inventory of Carbon & Energy Version 1.6a*

Conclusions

At Hunters Lane HWRC, using a Geosystem in place of a more traditional sheet pile method of construction, the following conclusions can be drawn.

- Through using a Geosystem in place of a sheet pile wall, a reduction in the CO_2 footprint of over 80% was possible for the materials and their import to site.
- The majority of this saving arose from using materials with a lower embodied CO_2 content than the steel sheet piles.
- Using the Geosystem approach meant that a financial saving of around 47% was also possible for the component materials and their delivery to site (i.e. not including the cost of construction).

Carbon Footprint

- The carbon footprint for the sheet pile option would have equated to approximately 393 Tonnes of CO_2. This is equivalent to flying from London to Edinburgh and back 35 times[6]. In order to offset that amount of CO_2, it would be necessary to plant around 560 Ash trees.

- The selection of a Geosystem solution for the Hunters Lane HWRC retaining wall refurbishment meant that there was a carbon saving of approximately 80%. This is equivalent to a carbon offset of approximately 450 ash trees[7].

[6] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[7] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

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Material change for a better environment

Sustainable Geosystems in Civil Engineering Applications

Modular Block Wall, Mansfield Community Hospital, Nottinghamshire

(Photograph courtesy of Tensar International Ltd).

As part of the redevelopment of Mansfield Community Hospital, a retaining wall was required to support a new car parking area. A Modular Block Wall Geosystem provided a cost effective and quicker solution than the initial proposal for a reinforced concrete wall, with the added benefit of significant CO_2 savings.

Mansfield Community Hospital Modular Block Wall Case Study

In the redevelopment of Mansfield Community Hospital in Nottinghamshire, a retaining structure was required to support a car park above the adjacent pavement and road. The programme of works for the project required that the retaining structure should be quick to construct, simple to install and capable of being constructed in stages. The project was commissioned by the Sherwood Forest Hospitals NHS Foundation Trust, with Skanska Innisfree as the developer, and the work was undertaken by North Midland Construction.

Key facts

The retaining wall was required to support an area of car parking.

The Geosystems solution that was adopted allowed the re-use of some 507 tonnes of site-won material which would otherwise have been sent to landfill for disposal, resulting in reduced construction waste from the project.

The re-use of the site-won materials meant that the planned import of higher grade granular fill, together with large volumes of concrete, was unnecessary.

The use of the site-won material resulted in a cost saving to the project of around 53%, and a 57% carbon saving.

Project details

Figures 1 and 2 illustrate the original proposal for a reinforced concrete wall and the Geosystems-based modular block wall that was adopted in its place.

Figure 1: *Detail of original proposed reinforced concrete wall design*

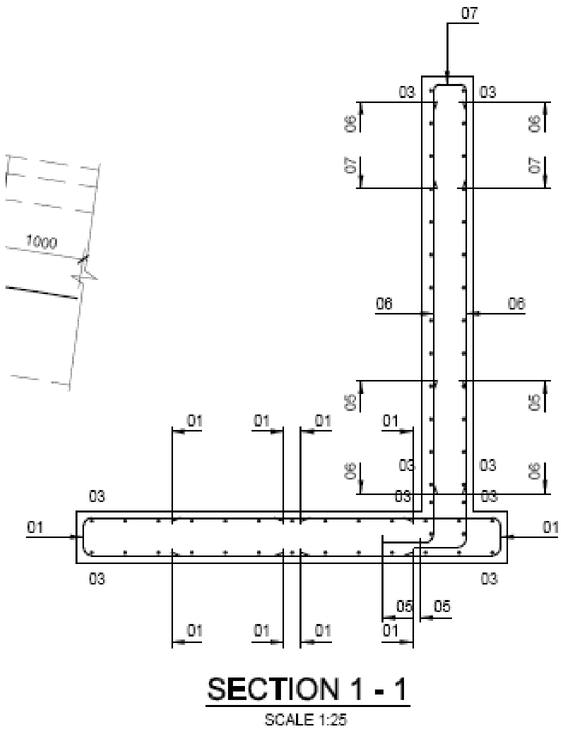
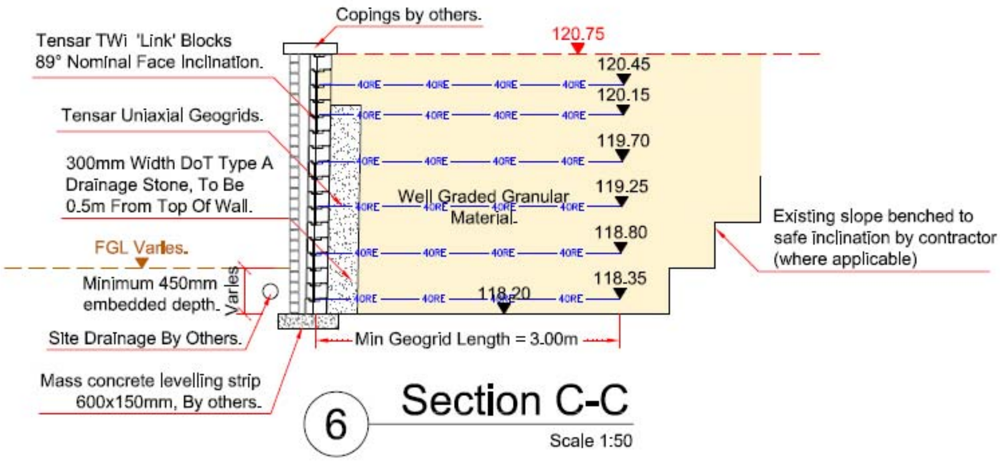


Figure 2: *Detail of Modular Block Wall design constructed at Mansfield Community Hospital*



Comparison of the two designs

Environmental and financial costs

Figure 3 illustrates the different approaches required to deliver the two alternative designs, and assigns the calculated values for embodied CO_2 to each stage.

Figure 4 does the same for the financial costs. The figures are taken from Tables 1 to 3 which follow, and further underlying data and calculations are provided in Tables 4 and 5 (which also follow).

Figure 3: Flowchart comparing the alternative options for construction of the retaining walls and their associated carbon footprints

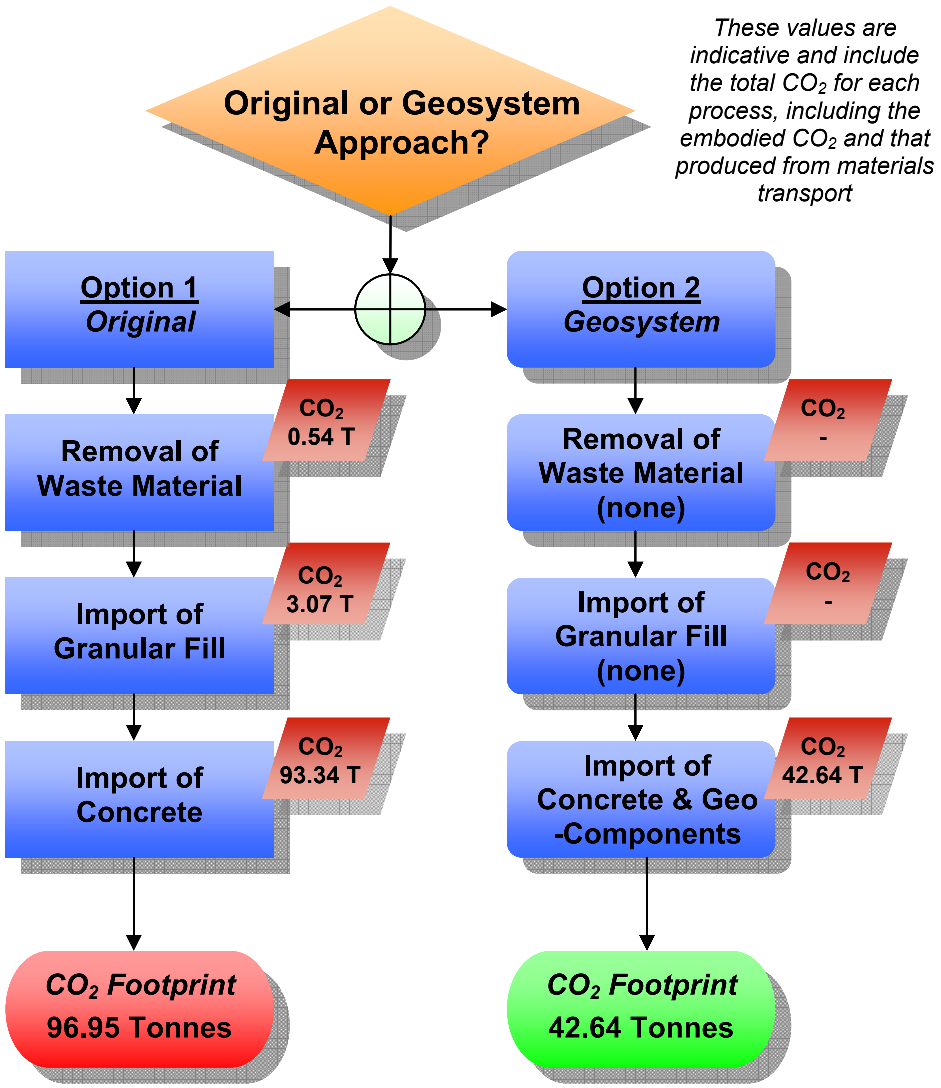
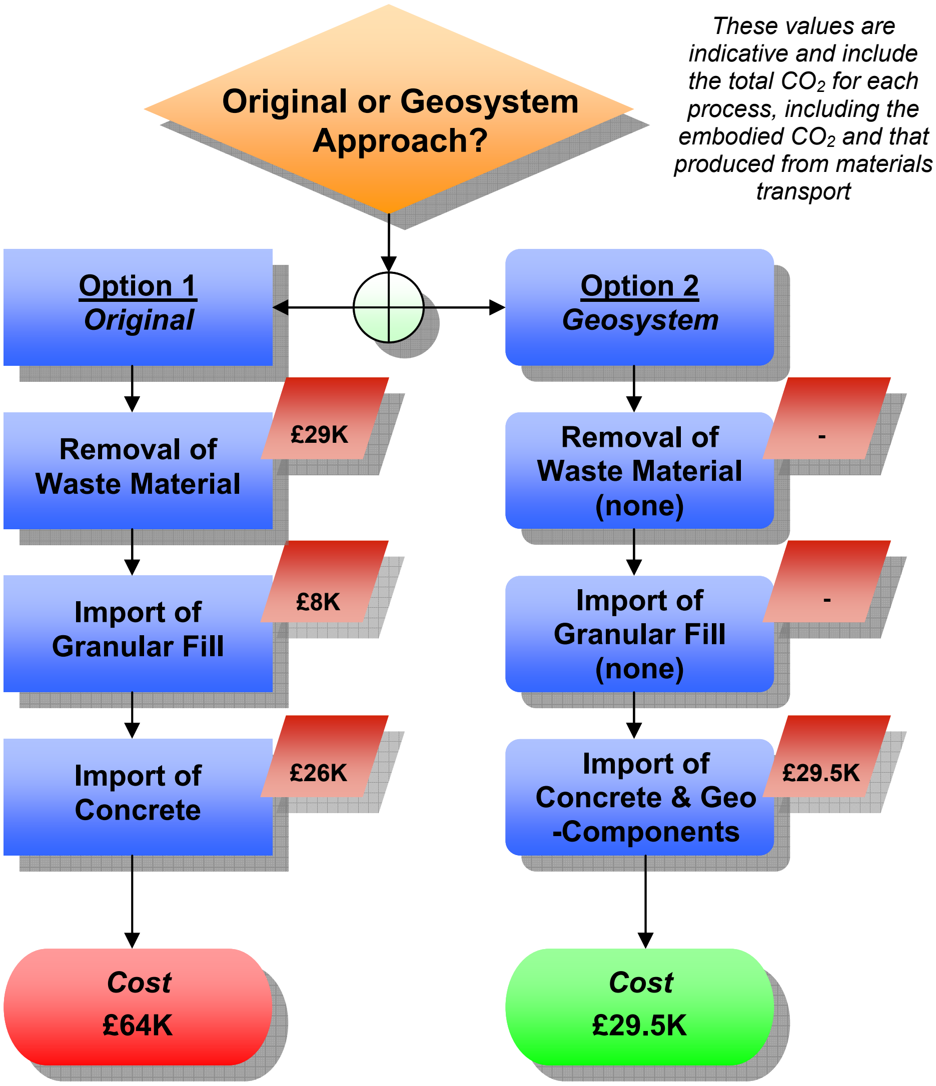


Figure 4: Flowchart comparing the alternative options for construction of the embankment and their associated financial costs



Supporting calculations

Disposal of waste materials

Substantial economic and environmental savings were achieved through the re-use of site-won materials and the incorporation of a modular block Geosystem.

The original proposal for an “L” shaped reinforced concrete wall (see Figure 1) would have required the import of granular fill from Bestwood Quarry. Instead, it was possible to screen and process site-won material on site and to incorporate it into an engineered Geosystem using geo-components to construct a modular block wall.

The re-use of the site won materials eliminated the need for 507 tonnes of waste material to be disposed of at Cavendish Lodge Farm landfill, some 7 miles from the site, as originally planned. This generated a saving of approximately £29,250 which would have arisen in haulage, landfill tax and gate fees. Additionally, the re-use of the site-won material meant that no granular fill import was required.

Eliminating the need for haulage related to off site waste disposal also significantly reduced the carbon footprint of the project. Transportation of 507 tonnes of waste material to the disposal site would have produced an estimated 0.54 tonnes of CO_2.

Table 1: Carbon & Cost Savings for **Waste**

Method	Material (Tonnes)	Total CO_2[1] (Tonnes)	Total Cost (£)
Reinforced Concrete Wall	507	0.54	29,250[2]
Modular Block Wall	0	0	0
Total Saving	**507**	**0.54**	**29,250**

Import of Fill Materials

The original reinforced concrete wall design required the removal of excess low grade material from site. To make up the ground to founding levels and provide the backfill for the reinforced concrete retaining wall, an equivalent amount of granular fill would have been required. With the original wall proposals the contractor had identified a suitable crushed rock granular material available locally from Bestwood Quarry, around 6.8 miles from the site. The total estimated cost for import of this material, including road haulage would have been £8,370.

This equates to 2.54 tonnes of embedded CO_2 for the fill material, resulting from the processes involved in excavation and crushing the quarried material. Transport of this material by road would have produced a further 0.53 tonnes of CO_2. By contrast, the selected Geosystems solution required no imported granular fill thereby producing no CO_2 emissions from transportation.

[1] *Values for CO_2 include embodied energy and that produced by haulage*
[2] *Includes costs for gate fee, tax and haulage*

Table 2: Carbon & Cost Savings for **Site Imports**

Method	**Material (Tonnes)**	**Total CO_2 (Tonnes)**	**Total Cost (£)**
Reinforced Concrete Wall	507	3.07	8,370
Modular Block Wall	0	0	0
Total Saving	**507**	**3.07**	**8,370**

Structural components

The original concrete wall option would have required 306 tonnes of concrete with an embodied CO_2 content of around 71.31 tonnes. The steel reinforcement within the wall would have had around 21.95 tonnes of embodied CO_2. To transport these reinforced concrete components to site would have produced 0.08 tonnes of CO_2 and cost £26,330 including delivery.

The engineered Geosystems ensured the stability of the site-won material used in the construction of the modular block wall. The geo-components comprised around 1,500m² Tensar 40RE uni-axial geogrid and a face area of around 208m² of Tensar TW1 blocks, with a further 208m² of facing bricks. These materials were imported to site by road and cost £2,950 for the geogrid, £9,370 for the blocks and £16,629 for the facing bricks, including haulage. Additionally, a lean mix concrete footing was required as a levelling layer under the base of the wall, at a cost of £560.

The geo-components used in the construction of the modular block wall had an embodied CO_2 content of around 0.27 tonnes for the Tensar 40RE geogrid, 13.72 tonnes for the Tensar TW1 blocks and 23.81 tonnes for the facing bricks. Additionally, the transport of the geo-components to site would have added 0.27 and 1.09 tonnes of CO_2 respectively.

Table 3: Costs and CO_2 associated with the **components**

Element	Total CO_2[3] (Tonnes)	Total Cost (£)
Reinforced Concrete Wall	71.39	26,330
Modular Block Wall	38.63	25,997
Total Saving	**32.76**	**333**

Basis for carbon and cost calculations

Table 4 provides the basis for the embodied CO_2 calculations used in this Case Study. This excludes any consideration of CO_2 emissions from transport to site or CO_2 produced during the formation of the Geomaterials.

Table 4: Calculations used to determine the embodied CO_2 of materials

Product	Material (and % by weight)	Mass (tonnes)	Embodied Carbon Value [4] in tonnes of CO_2 per tonne of material		Embodied Carbon (tonnes)
Concrete for retaining wall	Concrete RC35	306.07	Concrete RC35	0.241	73.76
Rebar	Steel	8.19	Steel rods (Virgin)	2.68	21.95
Footer concrete	Concrete RC20	19.12	Concrete RC20	0.13	2.49
Tensar 40RE	HDPE	0.50	HDPE	1.6	0.80
Tensar TW1 blocks	Concrete RC40	81.18	Concrete RC40	0.169	13.72
Granular fill	Aggregate	507.46	Aggregate	0.005	2.54
Brick Cladding	Facing Bricks Concrete	45795.39	Concrete (Facing Bricks)	0.52	23.81

Table 5 provides the cost factors used in this Case Study.

[3] *Values for CO_2 include embodied energy and that produced by haulage*
[4] *University of Bath & Carbon Trust, Inventory of Carbon & Energy Version 1.6a*

Table 5: Material Costs for the Original and Chosen methods and the Source for Costs

Material	**Unit price**	**Source of price**
Landfill	£45 / tonne for landfill tax and gate fee	WRAP (Comparing the cost of alternative waste treatment options)
Landfill haulage	£45 / tonne plus £55 / driver-hour	Haulage company
Retaining wall concrete	£86.04 / tonne	SPONS
Footer concrete	£29.16 / tonne	SPONS
Tensar 40RE	£1.70 / m²	Contractor
Tensar TW1 blocks	£45 / m² of face area	Contractor
Brick Cladding	£79.89 / per m²	Supplier / Manufacturer
Granular fill	£16.50 / tonne	Contractor

Conclusions

The Mansfield Community Hospital Case Study clearly demonstrates the financial and environmental advantages which can be realised through the selection of a Geosystems-based solution as an alternative to a conventional reinforced concrete wall by making optimum use of existing lower grade site-won materials. In this example, the use of the site-won material was achieved through the incorporation within an engineered design of a number of geo-components thereby avoiding the need for wastage of the excavated arisings and import of higher specification primary aggregates as backfill.

- The reduction of 507 tonnes of waste material equated to a saving of £29,250 by avoiding the associated transportation, landfill tax and gate costs. This also had a CO_2 saving of 0.54 tonnes.
- The removal of the need to import granular fill material led to a cost saving of around £8,370 and a CO_2 saving of 3.07 tonnes.
- Through the use of the site-won materials in combination with the geo-components, it was possible to achieve a substantial reduction in the quantities of concrete required. This led to a cost saving of £34,443 and a carbon saving of around 55.31 tonnes.

Carbon Footprint

- The Geosystems approach meant a reduction in the carbon footprint of the project of around 57% through using site-won materials in combination with an engineered design incorporating geo-components, compared to the originally proposed solution which relied heavily on imported granular fills and reinforced concrete.

- The solution saved approximately 55 tonnes of CO_2, equivalent to 6 round trips from London to Dublin by plane[5]. By way of comparison, it would be necessary to plant approximately 79 ash trees[6] to offset this.

[5] *Defra (2007) Department for Transport and AEA Energy & Environment. Guidelines to Defra's GHG conversion factors for company reporting*

[6] *Carbon Neutral (2009) Plant a Tree for Me, Carbon Offset Tree Planting in Lancashire www.carbonneutralfuel.co.uk, Webmaster: Hubmaker*

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Sustainable Geosystems in Civil Engineering Applications

M25 Widening Scheme

(Photograph courtesy of Naue Geosynthetics Ltd.)

During the summer of 2005 the M25 was widened between Junctions 12 and 15. The original scheme included a 4m high retaining wall at the side of the carriageway with a hollow concrete block drainage system running down the back of the wall. An alternative incorporating a Secudrain geo-composite was adopted, resulting in a number of environmental and economic benefits.

M25 Widening Scheme Case Study

The Secudrain was used along a 2.5km stretch of the motorway, requiring 10,000m^2 of the geo-composite. The cost of this material was approximately £3.00/m^2. The original scheme would have required a hollow concrete block system for back of wall drainage. The use of the geo-composite in place of the original method meant substantial CO_2 and cost savings could be realised.

The benefits of the alternative solution included:

- Easier and faster installation than conventional methods.
- Elimination of the need to import concrete hollow blocks to site.
- The drainage geo-composite could be attached full height in a single operation, reducing the hazard to the workforce and resulting in unhindered backfilling.
- Chemically inert and non-biodegradable materials.
- Significant cost savings over conventional materials.

The Secudrain geo-composite was imported by truck from Adorf in Germany, approximately 700 miles from site including a ferry journey between Dover and Calais of around 27 miles. The material was delivered in a single trip, and would have produced around 2 tonnes of CO_2 on top of the geo-composite material's embodied CO_2 of approximately 27 tonnes. As the Secudrain was significantly slimmer than the hollow concrete blocks, an extra 4,305 tonnes of backfill was required during installation. 4,305 tonnes of fill material would have had over 10 tonnes CO_2 in embodied energy, with a further 3.23 tonnes of CO_2 produced during the transport of the fill material if it was sourced within 10 miles of the site.

Approximately 2,526 tonnes of hollow concrete blocks with over 150 tonnes of embodied CO_2 would have been required for the back of wall drainage layer involving around 127 truck loads to haul the blocks to site. For the transport of the hollow concrete blocks from within 10 miles of site, around 3.8 tonnes of CO_2 would have been produced.

Using the drainage geo-composite in place of the hollow concrete blocks provided a cost saving as well as significant CO_2 savings.

Table 1: Comparison of Hollow Concrete Blocks and Geosystem

Method	**Material (Tonnes)**	**Total $C0_2$[1] (Tonnes)**	**Total Cost[2] (£)**
Hollow Concrete Blocks	2,526	157.9[3]	103,200[4]
Geocomposite	10	29.01	30,000[5]
Extra Fill	4,305	14.03[6]	71,032.5[7]
Total Savings	**-1,789**	**114.86**	**2,167.5**

[1] *Values for CO_2 include embodied energy and that produced by haulage*
[2] *Includes costs for product and haulage*
[3] *Assumed transport from within 10 miles of site*
[4] *£10.32 Per m^2 - cost of Hollow Concrete Blocks*
[5] *£3.00 Per m^2 - cost of Secudrain (inc transport)*
[6] *Assumed transport from within 10 miles of site*
[7] *£16.50 Per tonne – cost of Fill material*

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Sustainable Geosystems in Civil Engineering Applications

A4114 Abingdon Road Reconstruction, Oxford

(Photograph courtesy of Maccaferri Ltd)

Abingdon Road is a main arterial route heading south from Oxford city centre to the Southern By-Pass. It is an old road requiring regular maintenance due to its heavy traffic loads. To ensure its ability to accommodate future traffic growth, a long-term solution was required.

A4114 Abingdon Road Reconstruction

Oxfordshire County Council decided to reconstruct a 2km length of the road. The team which designed and carried out the work consisted of the Babtie Group (now Jacobs) as designer, and Isis Accord Contractor, under their term maintenance agreement.

Advice was sought from Maccaferri by Babtie for assistance in the design of the new road pavement. The main challenge was to limit the depth of excavation while providing an adequately strong pavement. There were archaeological remains that had to be protected under the highway and also services at shallow depth which would have been extremely expensive to relocate to allow the full pavement reconstruction depth needed for a traditional design.

Maccaferri proposed the geocomposite material Colbond Enkagrid TRC at formation level, with a steel Maccaferri Roadmesh as deep as possible in the bituminous layers to give maximum structural benefit. Initially, a 350m section of the highway was reconstructed using the approach above, which has been considered for the purposes of this case study.

The main benefits from using the Enkagrid and Roadmesh geo-componets were:

- The construction depth of the pavement could be reduced by 350mm.
- It was possible to maintain the necessary strength of the road with a reduced thickness of bituminous layers.
- There was no need to relocate the near-surface services beneath the road alignment.
- The shallow archaeological remains were preserved.

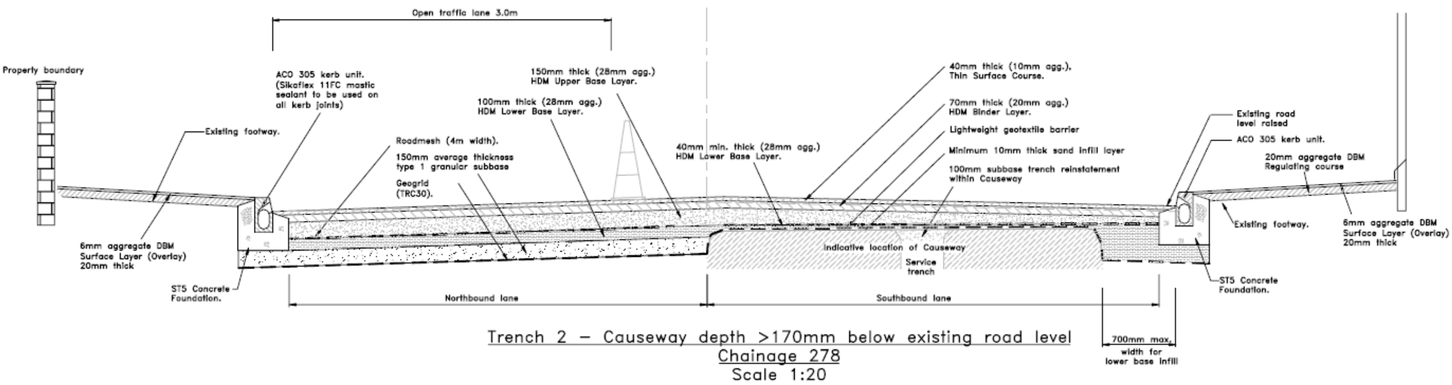
Figure 1: Reconstruction in progress (Photograph courtesy of Maccaferri Ltd)

The reconstruction of this 350m section of road yielded around 1,155 tonnes of waste materials. Using the geo-components for the road construction meant that it was possible to avoid removing a further 800 tonnes of material, due to the shallower excavation depth.

To remove 800 tonnes of waste would have required around 40 truck loads. For every 10 miles haul distance between the site and the disposal site, more than 1.2 tonnes of CO_2 would have been produced.

It can be assumed that the reduced volume of waste material also saved the import of 800 tonnes of bituminous fill material, saving around 4 tonnes of CO_2 that would have been embodied within the material.

Figure 2: Cross Section of works undertaken at Abingdon Road



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Reinforced Soil Block with Counterfort Drainage, Highley, Worcestershire

(Photograph courtesy of Huesker Ltd).

In June 2007 a major storm event caused several landslips along the Severn Valley Railway, including a 50m landslip at Highley, Worcestershire. Commissioned by the Severn Valley Railway with David Symonds Associates as Engineer, George Law Ltd undertook the remedial works.

Reinforced Soil Block with Counterfort Drainage, Highley

Over just a few hours on the night of 19 June 2007, some 166mm of rain fell in Worcestershire, triggering a sequence of slope failures along the Severn Valley Railway. Highley Station was the scene of one of the larger failures, with the railway tracks being washed away and a number of residential properties moving down the slope.

The track was constructed over Made Ground consisting of ash fill overlying Head Deposits. Underlying this, a historic clay shear zone was present overlying the solid geology. Post-failure investigations indicated that the failure had not re-activated the shear zone, but had washed away the more permeable upper slope layers.

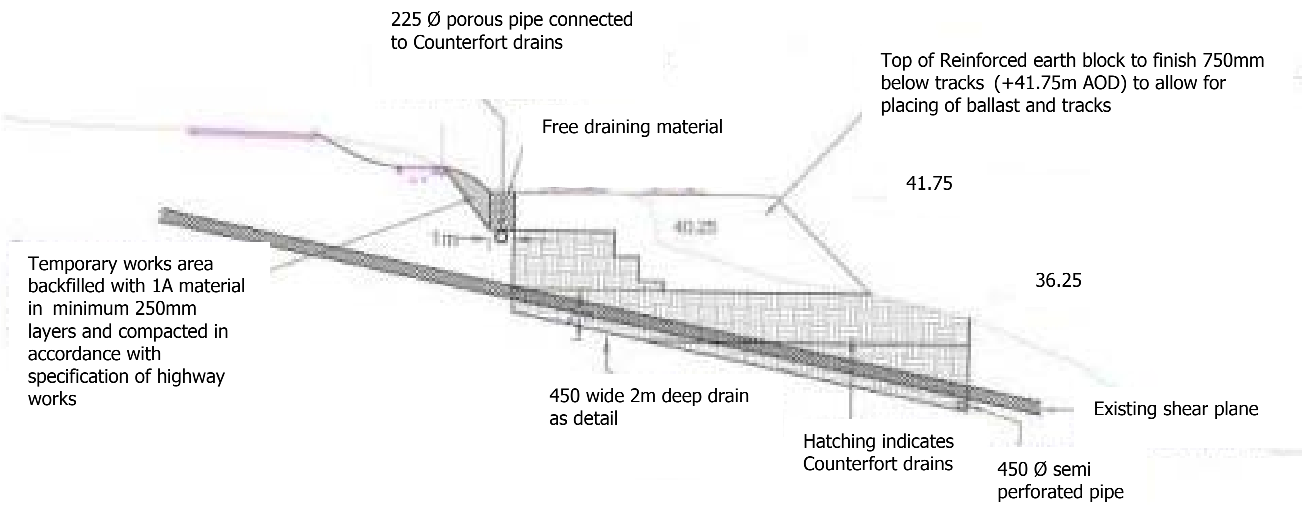
There was a need for a quick solution which took into consideration the cost constraints caused by the railway line being managed by a charitable organisation. The original proposal was for a contiguous bored pile wall, but given the various constraints this was rejected. Instead, a reinforced soil block with counterfort drainage was selected as the preferred method of remediation.

The main benefits of using the reinforced soil block method over a more traditional contiguous piled wall were as follows.

- Significant financial and environmental savings were possible.
- The wall was completed in a relatively short period of time, as required.
- The Highley slope stabilisation project showed that significant savings are possible through using a Geosystems approach in place of the more traditional contiguous piling technique.

To create the reinforced soil block structure for a 10m wide failed slope section, around 0.06 tonnes of Fortrac 30-3D geo-component would have been required. The embodied CO_2 content of the geo-component of this size is approximately 0.1 tonnes, with an additional 0.06 tonnes being produced during the transportation of the material to site. By contrast, the amount of concrete that would have been required to construct a 10m long section of the original contiguous piled wall would have been around 57.60 tonnes. This amount of concrete would have had an embodied CO_2 content of around 8.8 tonnes, with an additional 0.07 tonnes being produced during transportation.

Figure 1: Cross section of Geosystem method shown in EuroGeo paper number 193, (the cause, analysis and remediation of a slope failure at Highley, Severn Valley Railway, Worcestershire, UK)



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