YEAR 28 NUMBER 3 SEPTEMBER 2024

GEO build

SPECIAL EDITION OF THE DUTCH INDEPENDENT JOURNAL ON GEO-BUILDING MATERIALS












INTERNATIONAL SYMPOSIUM GEOSYNTHETICS AND SUSTAINABILITY DELFT – MAY 14TH 2024

GEOBUILD IS POWERED BY

MAIN SPONSORS

Westervoortsedijk 73
6827 AV Arnhem
Tel. +31 (0) 85 744 1300
www.enkasolutions.com

TenCate Geosynthetics Netherlands BV
Europalaan 206, 7559 SC Hengelo
www.tencategeo.eu

Naue GmbH & Co. KG
Gewerbestr. 2
32339 Espelkamp – Germany
Tel. +49 5743 410 *www.naue.com*

THE COLLECTIVE MEMBERS OF THE NGO ARE:

Ampèreweg 4, 3752 LR Bunschoten
Tel. 0031 (0)35 528 03 40
www.bonneveld.nl

Grafietstraat 11, 8472 EB Wolvega
Tel. 0031(0)561 613 114 *www.juta-holland.nl*

Phantom 3, 5126 RJ Gilze
Tel. 0031 (0)162 455 515 *www.tefab.nl*

Industriestraat 39, 9240 Zele – Belgium
Tel. 0032 52 457 411
www.bontexgeo.com

Cascademuur 38, 3991 VP Houten
Tel. 0031 (0)6 29 27 28 01
www.kwastconsult.nl

TenCate Geosynthetics Netherlands B.V.
Europalaan 206, 7559 SC Hengelo
Tel. 0031(0) 546 544811 *www.tencategeo.eu*

Westervoortsedijk 73, 6827 AV Arnhem
Tel. 0031(0) 85 744 13 00
www.enkasolutions.com

Naue Nederland B.V.
Goorsestraat 1, 7041 GA 's-Heerenberg
Tel. 0031(0) 6 19581068 *www.naue.com*

Tensar International B.V.
Helftheuvelweg 11, 5222 AV 's-Hertogenbosch
Tel. 0031(0) 73 624 1916 *www.tensar.nl*

Goorsestraat 1, 7041 GA 's-Heerenberg
Tel. 0031 (0)466 16 44 *www.genap.nl*

Mosweg 21, 7556 PG Hengelo
Tel. 0031 (0)74 763 0490 *www.nepocon.nl*

Trisoplast Mineral Liners
Oude Weistraat 17, 5334 LK Velddriel
Tel. 0031(0) 418 63 6030 *www.trisoplast.com*

Middelblok 154, 2831 BR Gouderak
Tel. 0031(0)182 37 73 27
www.geopex.com

Kierkamperweg 33, 6721 TE Bennekom
Tel. 0031 (0)88 166 2000
www.normecqs.com

Veilingweg 24, 6681 LA Bemmel
www. joostenkunststoffen.nl

Industriestraat 15, 8281 BN Genemuiden
Tel. +31 (0)38 385 48 66 *www.robusta.nl*

CDR International BV, Rijssen
Deltares, Delft
Cofra B.V., Amsterdam
Fugro, Leidschendam
Kiwa NV, Rijswijk
Rijkswaterstaat, Utrecht
Stybenex, Geldermalsen
Enviro Quality Control BV, Maarssen
Huesker Synthetic BV, Rosmalen
Witteveen + Bos, Deventer

PREFACE

Dear GEOBUILD readers,

In a world increasingly focused on sustainability, the construction sector is stepping up to make a difference with innovative eco-friendly materials and solutions. For NGO-IGS Netherlands, sustainability is a key topic, both locally in the Netherlands and globally. To address this, we organised the international symposium on 'Geosynthetics & Sustainability'. Related articles are featured in this special edition of Geobuild. Given the international focus, we publish this magazine in English.

The symposium was held on 14 May 2024. It was organised by the NGO-IGS (Nederlandse Geotextiel Organisatie, the Dutch Chapter of the International Geosynthetics Society, IGS) and the IGS-foundation. The event aimed to facilitate knowledge transfer on geosynthetics and sustainability. To connect with education and young people (students), it was hosted at the Technical University (TU) in Delft, The Netherlands. It was also streamed online with over 120 attendees. Suzanne van Eekelen (Deltares) chaired the symposium. Top experts from around the world presented state-of-the-art research and applications, highlighting the sustainability benefits of geosynthetics.

In this special edition you will find detailed articles as follows:
- **Robbin Schipper, Rijk Gerritsen and Suzanne van Eekelen**, Introduction to the International Symposium on Geosynthetics and Sustainability.
- **Jorge Zornberg,** Sustainability benefits provided by geosynthetic solutions in roadway applications.
- **Kent von Maubeuge** - Sustainable applications in hydraulic engineering.
- **Wim Voskamp** – Sustainable use of geosynthetics in the Netherlands.
- **Amir Shahkolahi, Jonathan Shamrock and Jabulile Msiza,** Sustainable use of geosynthetics in landfill applications.

The presentations and related articles show that geosynthetics contribute to numerous sustainability aspects in the civil engineering sector. Geosynthetics help reducing CO_2 emissions and reducing the use of primary raw materials. Climate-adaptive and sustainable solutions using geosynthetics are possible. Examples include improving flood defences, coastal protection, sustainable infrastructure solutions, water storage for periods of intense drought and water collection systems for extreme rainfall. Applications with geosynthetics lead to smarter solutions, greater robustness, lower emissions and reduce construction and maintenance costs.

From the Dutch perspective, our Environmental Cost Indicator (ECI – in Dutch 'Milieu kosten indicator – MKI') shows that we are globally ahead. The system is used in design assessments to determine the lowest environmental impact based on material and energy use. This allows for the comparison of building methods. Reducing environmental impact is becoming increasingly important for contracting and awarding projects, making the ECI an essential tool. The symposium discussions revealed that the world is watching with great interest how this system is implemented in the Netherlands, to stimulate sustainability in the civil engineering sector and reduce the carbon footprint.

Time is ticking. Together we must take significant steps forward to reduce environmental impact and make geosynthetics part of a sustainable future. Let's take this challenge together!

I hope you will enjoy this edition and find inspiration.
Be smart. Be sustainable.

Rijk Gerritsen
Editor-in-chief Geobuild Magazine

COLOPHON

Editor in chief Rijk Gerritsen
Text editor Jurjen van Deen
Editorial Board Adam Bezuijen, Piet van Duijnen, Suzanne van Eekelen, Paul ter Horst, Tara van der Peet

Production/Publisher Uitgeverij Educom
www.uitgeverijeducom.nl
www.vakbladgeotechniek.nl
For more information NGO (Dutch chapter of the IGS)
Tel. +31 (0)6 50 64 67 60
mail@ngo.nl *www.ngo.nl*

GeoKunst/GeoBuild is published by the Nederlandse Geotextiel Organisatie (NGO). The magazine is published four times a year and is sent to subscribers or on request. The NGO is the official Dutch representation of the International Geotextile Society (IGS). The NGO is a non-profit association consisting of knowledge institutes, laboratories, inspection and certification bodies, engineering firms, contractors, government agencies, manufacturers and suppliers. The NGO promotes knowledge about sustainable design, responsible use and construction with high-quality geosynthetics with many applications in civil engineering, hydraulic engineering, environment and construction.


Robbin Schipper
Solmax


Rijk Gerritsen
Naue


Suzanne van Eekelen
Deltares

GEOSYNTHETICS AND SUSTAINABILITY INTERNATIONAL SYMPOSIUM IN DELFT

Introduction

On May 14th, 2024, the NGO – IGS Netherlands organized an international symposium in collaboration with the IGS and a number of corporate partners. The topic of the symposium was 'Geosynthetics and Sustainability'. The symposium hosted a number of renowned experts who provided insights into the latest research and applications, emphasizing the crucial role of geosynthetics in achieving environmental objectives.

We look back on a successful symposium that was well attended, with approximately 70 people in person and more than 120 people online. The insights presented at the symposium, along with the discussions between presenters and attendees, serve as an excellent basis for exploring the application of environmentally friendly solutions with geosynthetics.

Presentations

The symposium was chaired by Suzanne van Eekelen, who stressed that the rise in global temperatures and consequent climate change require a strong reduction in greenhouse gas emissions. Geosynthetics can properly and responsibly contribute to making the construction sector more sustainable. They can significantly enhance the sustainability of civil and hydraulic engineering by contributing to CO_2 reduction, reducing the use of primary raw materials, enabling faster construction, reducing risks, and providing cost efficiency compared to traditional construction methods.
With this symposium, the NGO and IGS aim to facilitate knowledge transfer on geosynthetics and sustainability. Given the wide range of geosynthetic applications, the presentations covered a variety of interesting topics. Also, sustainability aspects were highlighted from different angles and applications.

Roadway applications

Jorge Zornberg of the University of Texas at Austin presented the sustainability benefits of geosynthetics in roadway applications. Given the worldwide total quantity of roads over 64 million km, the use of geosynthetics in roadways can have a pronounced benefit. Zornberg stated that if roads in the world would be optimized using geosynthetics, the resulting CO_2 reduction would be in proportion to the CO_2 capturing by a forest area multiple times in size of the Netherlands.

Figure 1 – NGO Netherlands/IGS Foundation members startup meeting with from left to right: Suzanne van Eekelen, Anant Kanoi, Ivo Huiskes, Cihan Cengiz, Peter Legg, Robbin Schipper, Sam Allen, Adam Bezuijen, Jacques Cote, Jorge G. Zornberg, Boyd Ramsey, Rijk Gerritsen, Wim Voskamp.

SUMMARY

The rise in global temperatures requires a strong reduction in greenhouse gas emissions. Geosynthetics can enhance sustainability in civil and hydraulic engineering by significantly reducing CO_2 emissions (32-89%) and energy use (up to 85%) compared to traditional materials. They also reduce the need for transporting heavy materials like sand and gravel. The EU aims to reduce emissions by 35% by 2035 and achieve climate neutrality by 2050, with the Netherlands targeting a 55% reduction by 2035. This symposium, organized by the NGO and IGS, aims to facilitate knowledge transfer on geosynthetics and sustainability. Top experts from around the world presented state-of-the-art research and applications, highlighting the sustainability benefits of geosynthetics. Detailed articles on the presented subjects are published in this magazine.

The benefits of geosynthetics are pronounced in the asphalt overlay in case of retrofitting, original pavement, base and subbase layers. Zornberg presented a number of researches and real-world applications to quantify this benefit.

The design alternatives with geosynthetics presented result in a decrease of equivalent CO_2 emissions varying between 11,6% and 50,1% compared to traditional (without geosynthetics) solutions. The presentation by Zornberg shows that the designs applying geosynthetics are proven in actual projects and result in significant improvements in sustainability.

Hydraulic engineering

Kent von Maubeuge (Naue) presented the sustainable applications of geosynthetics in hydraulic engineering. The presentation indicated and stressed the enormous environmental challenges humanity is facing. These are the result of global warming as well as a lack of water availability and changes in rain intensity. The challenges are often a result of human behaviour and choices made in the past, as we tend for example to build close to rivers and levees. Without space, large river discharges can lead to flood events with enormous effects.

One of the potential applications of geosynthetics is the use of Geosynthetic Clay Liners (GCL) to function as a barrier in hydraulic applications. These materials can be installed both below and above the groundwater table.

The presentation of Von Maubeuge showed that various embankments have been successfully repaired using a double layer GCL system, that is quick to install and can be accurately placed (see figure 3). The use of GCL materials is a sustainable alternative to existing methods as it requires less transport and fewer machines on site to install. Replacing compacted clays by GCLs leads to less excavated material. This results in a lower impact for the environment as fewer material will need to be excavated and transported to spoil locations or landfills. Another important benefit is the water consumption of these materials. Compared to compacted clays the GCL material requires no artificial watering, which can be very significant with compacted clays used in a dry region.

Table 1 – Symposium program overview with presenters

	Subject title	*Presenter/author*
1	Sustainability benefits of geosynthetics in roadway applications	Jorge G. Zornberg
2	Sustainable applications of geosynthetics in hydraulic engineering	Kent von Maubeuge
3	Sustainable use of geosynthetics in landfill and hydraulic applications world-wide	Boyd Ramsey
4	Geosynthetics in the Netherlands: Today's status in sustainability	Wim Voskamp
5	IGS initiatives to support sustainable development	Sam Allen
6	IGS Foundation contribution to sustainability	Jacques Cote

Figure 2 – Presentation Jorge Zornberg of the University of Texas at Austin on the sustainability benefits of geosynthetics in roadway applications.

Figure 3 – Presentation Kent von Maubeuge with Geosynthetic Clay Liners (GCL) as barrier installed with pre-impregnated overlaps at the Oder levee (Germany) to replace a thick and compacted clay layer.

Landfill and hydraulic applications

Boyd Ramsey presented on the sustainable use of geosynthetics in landfill and hydraulic applications world-wide. He highlighted the challenges we face today, given the population growth of the planet over the past centuries.

The presentation emphasized the different application of geosynthetics and their sustainability benefit. A striking example was the comparison between geosynthetic drainage materials and natural alternatives. By applying geosynthetics a significant saving of natural materials can be

Figure 4 – Example using geosynthetics in landfills with geomembranes and drainage mats by Boyd Ramsey.

Figure 5 – Presentation Sam Allen on IGS initiatives to support sustainable development.

made. Furthermore, geosynthetics are often a good substitute in situations where natural resources are not available.

Ramsey highlighted the standardization work that has been carried out in the past to quantify the benefits of geosynthetics and provide a framework for the application of the various products.

As an important step forward, the IGS has selected OneClick LCA as the platform for all NGO-IGS members to compare the sustainability performance of different solutions. The tool allows members to input both traditional methods and methods using geosynthetics to quantify the sustainability benefits. Ramsey's presentation concluded with an important paradigm: "You can only change the world by changing your own behaviour. No step is too small to contribute".

Sustainability in the Netherlands

Wim Voskamp presented the applications of geosynthetics in the Netherlands and the status in sustainability. The presentation gave a good overview of various applications with geosynthetics making a real benefit both in sustainability as well as increasing the service life of civil engineering structures and applications. The applications shown examples with soil improvement, base reinforcement, piled embankments, reinforced foundations under roads, reinforced slopes and walls, hydraulic applications and geomembranes.

The presentation highlighted the important advantages of geosynthetics, both economically as well as in sustainability. The various publications with LCA analyses indicate the benefit in CO_2 and energy savings from 30 up to 89%. Voskamp explained the target of the Netherlands to reduce emissions by 55% by 2035 and 100% by 2050. These targets are ambitious and challenging to reach. Another big program is the circular use of materials having a target of 50% of primary raw materials to be circular by 2030.

The presentation showed that projects in the Netherlands are awarded not only based on pricing, but also on performance, quality aspects and environmental costs. A fictitious discount is awarded when a tender proposal performs exceptionally on one of these aspects. The basis of the awarding at tenders is the Environmental Cost Indicator (ECI, in Dutch MKi) which is used to determine and assess the environmental impact costs.

Voskamp showed that there is also a great potential to reduce emissions with the production of geosynthetics by use of recycled polymers, biobased polymers, re-use and recycling of geosynthetics.

The IGS and the IGS Foundation

Sam Allen and Jacques Cote presented the IGS initiatives to support sustainable development and the contribution of the IGS Foundation to sustainability.

The presentation by Allen emphasized the importance of reducing the use of natural resources and construction materials (figure 5). The majority of construction materials is used in making concrete and asphalt. Geosynthetics can make a significant contribution in reducing the amount of construction materials. The presentation shows the efforts made by the IGS in highlighting the use of geosynthetics and the important benefits of geosynthetics for sustainable development. Part of the efforts by the IGS resulted in the "Did you know?" campaign, showing the benefits of the use of geosynthetics in various applications in small snip-its. The IGS is also involved in discussions with the European Commission regarding microplastics. An IGS e-Book has been published as well as the OneClick LCA tool to quantify the benefits of geosynthetic solutions.

The presentation by Cote highlighted the work of the IGS Foundation, whose mission is to support educational initiatives on providing an understanding, and promoting the appropriate use, of geosynthetic technology worldwide for the benefit of humanity. The Foundation has a board of leading experts dedicated to supporting initiatives that benefit all stakeholders in the industry and humanity at large.

Discussion and conclusion

The symposium concluded with an interesting discussion between both the audience and the panel members on the sustainable use of geosynthetics. Questions focused on topics such as the impact of freezing/thawing cycles in case of embedded geogrids to roads or railways, the contribution of geosynthetics to climate change mitigation, and the integration of the Environmental Cost Indicator as a selection tool in projects.

After the concluding remarks there was time for socializing and networking at the PSOR Café at the TU Delft. The presentation slides are available on www.ngo.nl. The NGO-IGS would like to thank all the presenters and attendees for their participation and contributions to the symposium. ●

Jorge G. Zornberg
Professor and Joe J. King Chair in Engineering,
The University of Texas at Austin, Austin, TX, USA

SUSTAINABILITY BENEFITS PROVIDED BY GEOSYNTHETIC SOLUTIONS IN ROADWAY APPLICATIONS

Introduction

The world's roadway system has been reported to reach a total length of 64,285,009 km [1]. The extent of the roadway system is so significant that its total length would encircle the Earth over 1,600 times if combined. Geosynthetics have provided sustainable alternatives in roadway projects, representing a substantial portion of the total usage of geosynthetics in civil infrastructure. Yet, considering the significant extension of roadway projects worldwide, geosynthetics are still employed in a comparatively small fraction. Accordingly, the opportunities to achieve sustainability benchmarks by increasing the presence of geosynthetics in roadways are simply enormous.

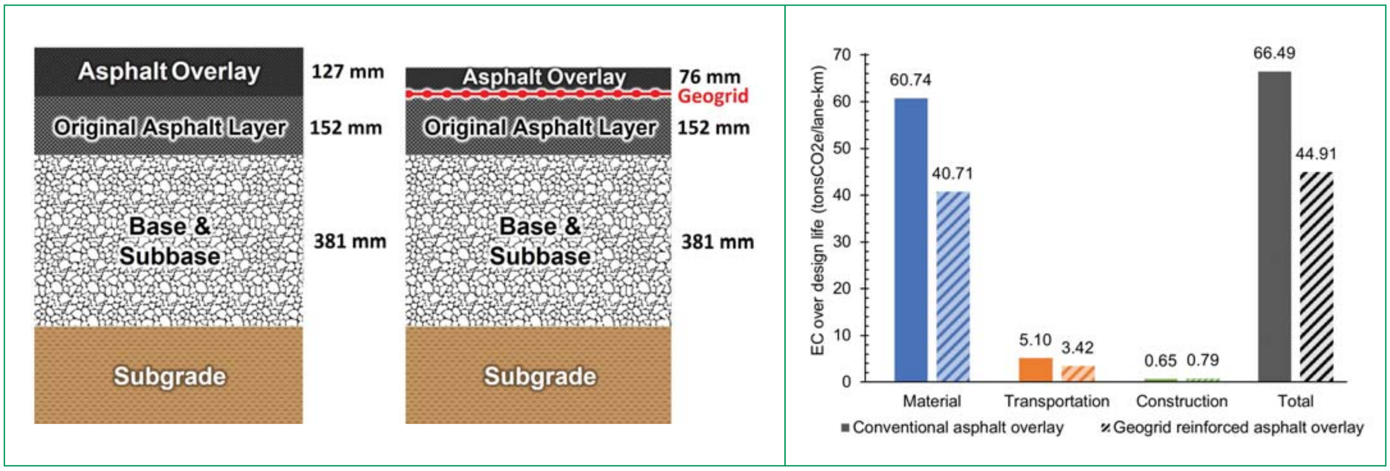
One or more of the various geosynthetic functions have been used in roadway applications for separation, filtration, reinforcement, stiffening, and drainage [2]. Listing the various roadway applications according to the position of the layers in a roadway structural package where the geosynthetics are installed (from top to bottom), they can be summarized as follows: (1) mitigation of reflective cracking in structural asphalt overlays, (2) stabilization of unbound aggregate layers, (3) reduction of layer intermixing, (4) reduction of moisture in structural layers, (5) stabilization of soft subgrades, and (6) mitigation of distresses caused by shrink/swell subgrades. This study focuses on quantifying the carbon footprint for six roadway projects, each involving at least two alternative designs: One with and the other without using geosynthetics. The sustainability benefits of selecting a design alternative that uses geosynthetics were evaluated by conducting carbon audits for the alternative designs for each roadway project. Details on the methodology and various case studies are provided by Zornberg et al. (2024) [3].

Projects involving Mitigation of Asphalt Reflective Cracking

A relevant case study involving the use of geosynthetics in asphalt overlays is the rehabilitation of Texas State Highway (SH) 21. The Texas Department of Transportation (TxDOT) designed and implemented a rehabilitation program to restore the roadway's serviceability and to improve resistance against reflective cracks and other distress that may occur due to the moisture fluctuations in the expansive clay subgrade and the repeated heavy truck loads. TxDOT pavement designers considered an initial rehabilitation solution that included treating the pre-existing distresses with half or full-depth repairs, applying a binder tack coat, and constructing a 127-mm-thick hot mix asphalt (HMA) overlay. However, additional considerations led to a revised overlay design involving the use of geosynthetic interlayers. Specifically, TxDOT eventually adopted the overlay design, which involved incorporating a polymeric geosynthetic reinforcement with a reduced (76-mm-thick) HMA overlay thickness (see figure 1a).
The Embodied Carbon (EC) quantifies the total greenhouse gas emissions that are associated with the production, transportation, construction, and other stages of a product or system's lifecycle, excluding its operational use and end-of-life disposal. The results of the analysis are summarized in figure 1b, which includes the EC values related to the different stages (material, transportation, construction) for the two alternative pavement designs and the total EC values. The carbon audit results are quantified in tonnes of carbon dioxide equivalents per lane-km (tCO_2e / lane-km). This standard unit for measuring carbon footprints allows different greenhouse gases to be expressed in terms of the amount of CO_2 that would have the same global warming potential. By using CO_2 equivalents, the total impact of various greenhouse gases, such as methane (CH_4) and nitrous oxide (N_2O), can be combined and reported as a single figure. A breakdown of EC for individual pavement layers reveals that the geosynthetic solution's carbon footprint showed a reduction of 32.4 % compared to the conventional overlay design.

Carbon Audit in Projects Involving Stabilization of Unbound Aggregate Layers

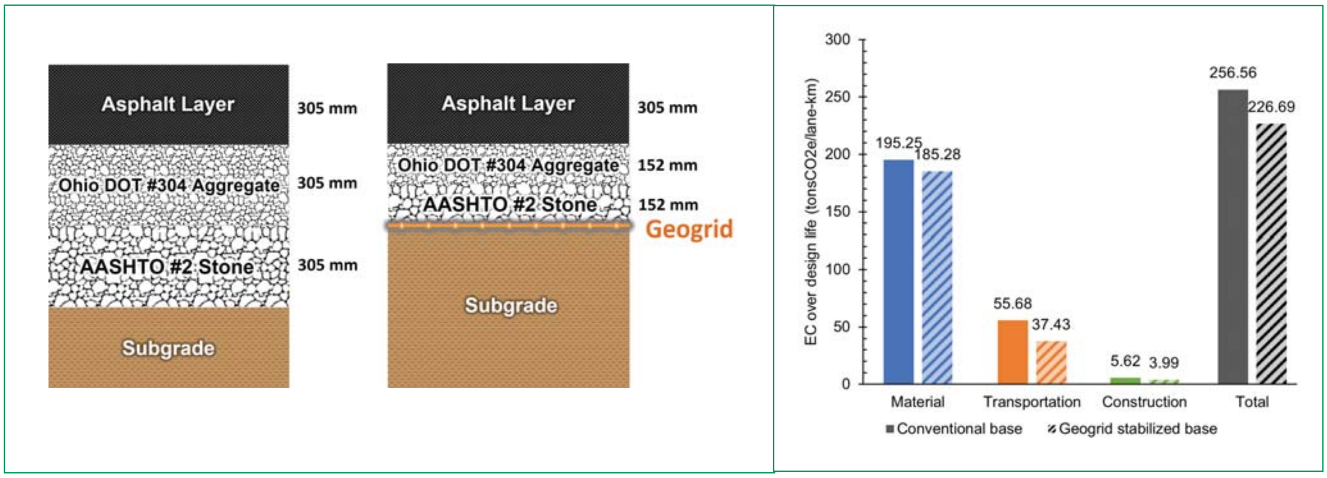
The reconstruction of Interstate Highway 90 (I90) near Ashtabula, Ohio, USA, is a project that illustrates the adoption of geosynthetics to stabilize unbound aggregate layers. Along a section of I90, the Ohio Department of Transportation (ODOT)



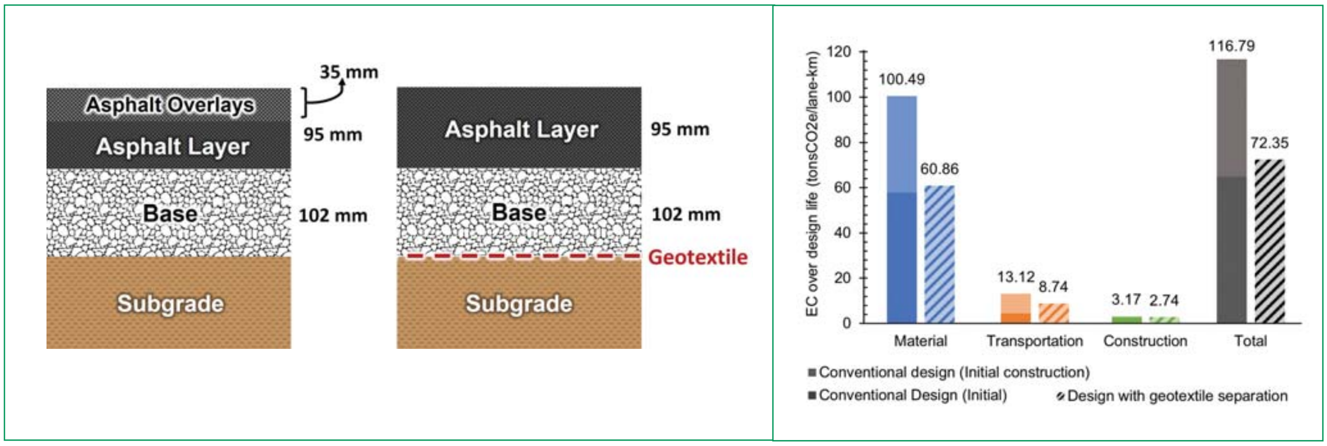
Figures 1a & b – Case study involving mitigation of reflection cracks: (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024).

SUMMARY

The opportunities to achieve sustainability goals by making more extensive use of geosynthetics in roadways are massive. This paper aims to illustrate the sustainability benefits of adopting geosynthetics in roadway design. This is accomplished by quantifying the carbon footprint for six roadway projects, each involving at least two alternative designs: One with and the other without geosynthetics. The analyses indicate that the design alternatives involving geosynthetics always proved more sustainable than the conventional (without geosynthetics) alternatives, resulting in savings in the total carbon footprint that ranged from 16.3 to 44.44 tCO_2e per lane-km.



Figures 2a & b – Case study involving stabilization of unbound aggregate layers: (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024)



Figures 3a & b – Case study involving reduction of layer intermixing: (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024)

removed the existing pavement structure and layers of subgrade, added additional lanes to the highway in both directions and reconstructed the entire pavement. The project site's proximity to Lake Erie results in a weather phenomenon where cold air passes over warmer lake waters, picks up moisture, and then deposits it as snow on the downwind shores (lake-snow effect). This made the available time construction window particularly short. Thus, adopting a design that would minimize construction time was particularly important. The original pavement design by ODOT involved an undercut of 915 mm to be replaced by 305 mm of AASHTO #2 stone overlain by 305 mm of smaller-size aggregate and 305 mm of asphalt layer. However, incorporating a geosynthetic layer in the design led to significant cost-savings and construction benefits. Specifically, adopting a biaxial geogrid beneath the AASHTO #2 stone layer would reduce the undercut by about 610 mm (see figure 2a). Consequently, the amount of aggregate used on the project was cut in half, resulting in significant cost savings. In addition, replacing 305 mm of aggregate with a geosynthetic-stabilized layer resulted in a significantly shorter construction time.

The assessed carbon footprints are presented in figure 2b, which includes the EC values corresponding to different construction phases and the total EC values. The total emission, excluding the asphalt layer, reduces to 37.80 tCO_2e per lane-km, which corresponds to a reduction of 44.1 % in relation to the conventional design.

Carbon Audit in Projects Involving Reduction of Layer Intermixing

The construction of several field test sections in a low-volume road by the Virginia Department of Transportation (VDOT) in Bedford County, Virginia, USA, represents a good opportunity to evaluate the use of geosynthetics to reduce layer intermixing. As part of this VDOT study, nine 15-m-long test sections were constructed, including three control sections, three test sections with a geotextile separator, and three test sections with a geogrid. The roadway sections evaluated in this study include control sections and sections with geotextile separators (see figure 3a). The service life of the test sections was estimated based on the equivalent single axle load (ESAL) corresponding to a rutting depth of 20 mm. While sections constructed with geotextile separators reached a traffic volume of over 100,000 ESALs without rehabilitation, the control sections required two rehabilitation activities to reach such traffic volume.

The carbon footprints for the two design alternatives are shown in figure 3b in terms of EC values for the individual construction phases and the total EC for each design alternative. While the EC components associated with subgrade and base courses are the same for both alternatives, installing a geotextile separator avoids rehabilitation cycles, which would involve additional asphalt overlays. As a result, the EC of the asphalt layers is reduced from 105.85 tCO_2e to 58.15 tCO_2e.

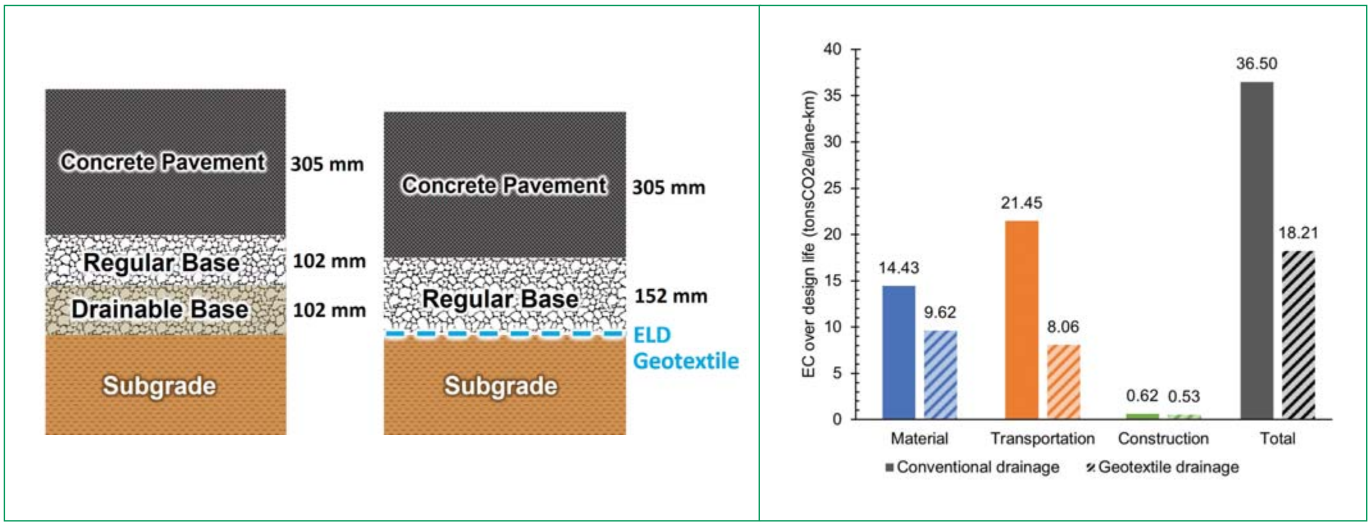
Carbon Audit in Projects Involving Moisture Reduction in Structural Layers

The construction of the Daniel Boone Bridge along Interstate 64 by the Missouri Department of Transportation (MoDOT) represents a good example illustrating the application of geosynthetics to reduce moisture in structural layers. A new pavement approaching the bridge was also needed. However, proximity to the river resulted in a high water table beneath the pavement; thus, reducing moisture in the base course by mitigating upward moisture infiltration was essential. Several alternatives were considered to address the high water table. One pavement alternative considered a 102 mm thick layer of drainable aggregate to be placed beneath a 102 mm aggregate base layer. However, drainable base costs, on average, $40/ton, whereas regular base aggregate costs $12/ton. In turn, another alternative that used an in-plane draining geotextile was considered. Accordingly, 50 mm of the total regular and drainable base materials were replaced by an in-plane draining geotextile, providing separation and subgrade stabilization to the roadway (see figure 4a). The geotextile alternative both lowered costs and met drainage requirements.

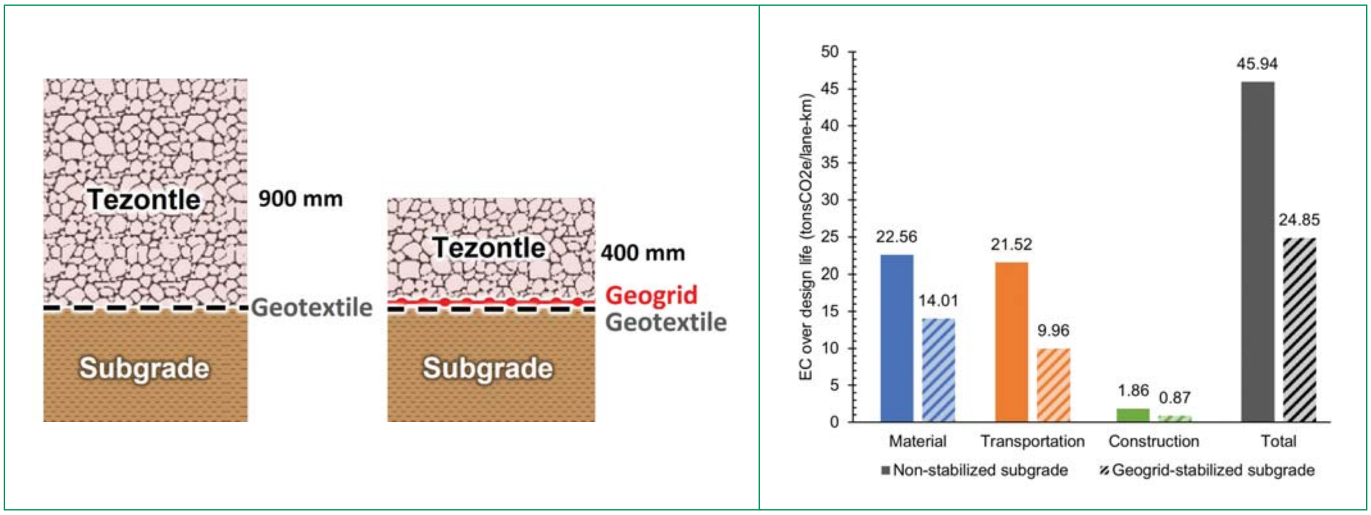
The results, summarized in figure 4b, show a reduction from 14.43 tCO_2e to 9.62 tCO_2e for material production, from 21.45 tCO_2e to 8.06 tCO_2e for transportation, and from 0.62 tCO_2e to 0.53 tCO_2e for construction. Among these components, the most significant change is observed in the transportation stage, which shows a 62.4 % improvement. The total emissions were estimated as 36.50 tCO_2e and 18.21 tCO_2e for conventional and geotextile drainage designs.

Carbon Audit in Projects Involving Stabilization of Soft Subgrades

The New International Airport of Mexico City is a major engineering endeavor initially planned to sustain 70 million passengers and 540,000 landings and take-offs yearly. The airport was planned at a location distanced 15 km from the city center over the former Lake Texcoco and will occupy over 40 million square meters of surface area. Due to the presence of soft lacustrine clay, the subgrade soil was saltier than seawater and settled at a rate of 15 to 20 mm a month. Chemical stabilization was not a viable alternative because of the presence of volcanic basalt, and other traditional methods to stabilize the ground did not succeed. Preliminary trials using geosynthetics, however, proved to result in a technically feasible low-cost alternative to stabilize the very soft subgrade. Construction alternatives included the use of an aggregate locally known as Tezontle (a local volcanic rock often used in construction in Mexico) to stabilize the ground. Specifically, two alternatives were considered in the design to stabilize the soft subgrade, including a conventional and a geosynthetic-stabilized option. The conventional alternative, without geosynthetic stabilization (i.e., non-stabilized alternative), involved placement of a 900-mm-thick layer of Tezontle, while the geosynthetic-stabilized alternative involved using a geogrid layer overlain by a reduced, 400-mm-thick Tezontle layer (see figure 5a).



Figures 4a & b – Case study involving moisture reduction in structural layers: (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024).



Figures 5a & b – Case study involving stabilization of soft subgrades: (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024).

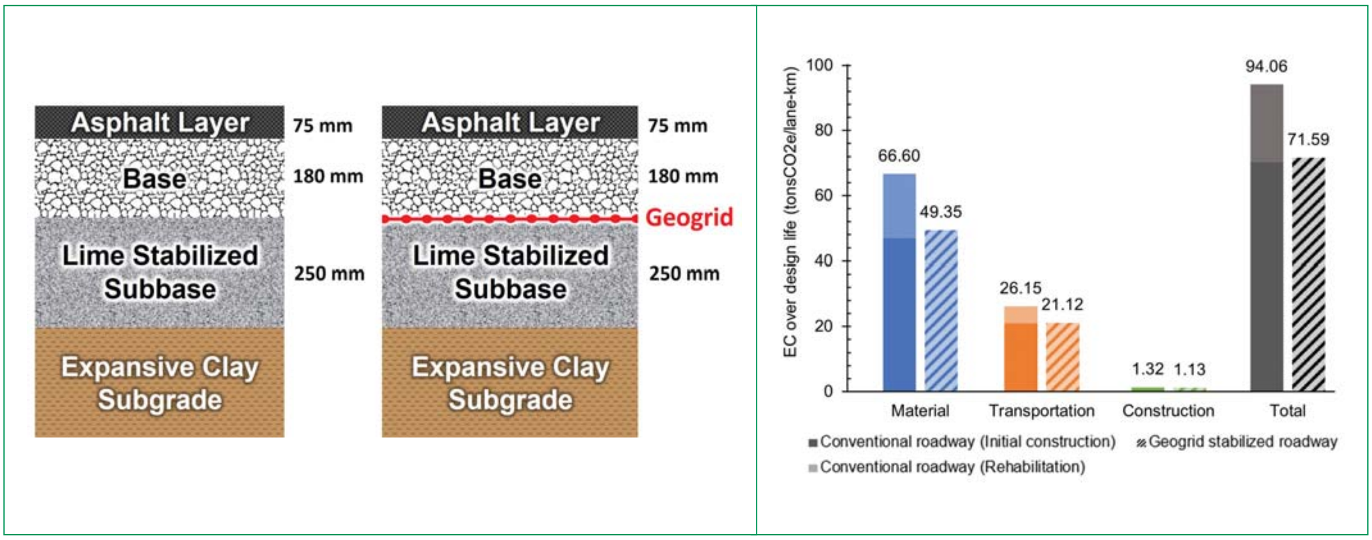


Figure 6a & b – Case study involving mitigation of distress caused by expansive clay subgrades (a) Cross-sections of conventional and geosynthetic solutions; (b) Carbon audit results showing contribution of different phases (source: Zornberg et al. 2024).

The results of the carbon audit, presented in figure 5b, demonstrate that significant benefits can be achieved by including the geogrid layer. The geogrid-stabilized design improves the EC values associated with all construction stages, yielding emission reductions of 37.9 % for material production, 53.7 % for transportation, and 53.4 % for construction. With these improvements, the total EC reduced from 45.94 tCO_2e to 24.85 tCO_2e – yielding an overall benefit of 45.9 %.

Carbon Audit in Projects Involving Mitigation of Distress Caused by Expansive Clay Subgrades

Farm-to-Market Road 1915 (FM 1915) extends approximately 32 km in Milam County, Texas, USA. Sections of this road are founded on highly expansive clay subgrades and have been reported to have extensive distress, particularly in the form of longitudinal cracks. The Texas Department of Transportation (TxDOT) rehabilitated the damaged section of FM 1915 in 1996 when experimental test sections were constructed to evaluate the performance of geosynthetic stabilization of the base course in mitigation of the damages induced by the expansive clay subgrade. The test sections extended for approximately 4 km, including a control (without geosynthetic) section and a test section constructed by placing a biaxial geogrid between their subbase and base. Both sections were constructed using the same base thickness of 180 mm, with the only difference being the presence of the biaxial geogrid in one of the sections (see figure 6a).

Each condition survey documented the severity and extent of the environmental longitudinal cracks. Geosynthetic-stabilized test sections performed significantly better than the control test section. A comparison of the performances of sections constructed using the conventional design and the geogrid-stabilized base revealed that using a geogrid to stabilize the base layer led to reduced maintenance costs and extended roadway service life. The conventional design section (without geosynthetics) exceeded the target of 15% longitudinal cracks only after 9.5 years of service, indicating the need for adding an overlay to extend its service life. However, geosynthetic-stabilized section performance was acceptable for at least 15 years.

The results of the carbon audit are presented In figure 6b in terms of total emissions and the contribution of the various construction stages. While the stabilized design results in slightly higher initial construction emissions for the geosynthetic design alternative (due to the inclusion of the geogrid layer with no pavement thickness reduction), rehabilitation involving the construction of an overlay led to an increased final EC value for the conventional design alternative. Overall, the total EC is estimated to be 71.59 tCO_2e for the geogrid stabilized alternative, which corresponds to a reduction of 23.9 % compared to the conventional design, with a total EC of 94.06 tCO_2e.

Conclusions

This paper presents the results of carbon audits conducted to illustrate the sustainability benefits of adopting design alternatives that involve the use of geosynthetics in roadway applications. While carbon footprint predictions are project-specific, comparing conventional design alternatives and geosynthetic design alternatives evaluated in this study showed that the geosynthetic design alternatives consistently provided a lower carbon footprint for six roadway applications. In all case studies evaluated in this investigation, geosynthetics were adopted as an alternative design to achieve enhanced roadway performance or maximize cost-savings, but without consideration of the potential sustainability benefits. Consequently, the reduction in carbon footprint is expected to be further optimized if designers consider it an additional criterion when selecting alternatives (e.g., by reducing the thickness of high-EC materials such as asphalt or chemically stabilized layers).

Considering for illustration purposes that the case histories evaluated in this study are representative of the six roadway applications discussed in this paper, an average reduction of 26.29 tCO_2e per lane-km in carbon footprint could be expected when adopting a geosynthetic design alternative instead of a conventional design. Assuming that the costs (and carbon footprint) of the roadway projects evaluated in this study are amortized over a typical roadway design life of 15 years, these projects point to an annual average reduction of 1.75 tCO_2e per lane-km-year in carbon footprint. Now, considering the reported world's roadway network of 64,285,009 km (and assuming two lanes per road), this results in a potential annual average reduction of 225 million tCO_2e per year in carbon footprint if the world roadway network were to benefit from designs involving geosynthetics. This is equivalent to the CO_2 sequestered by approximately 100 million hectares of forest in a year – or a forest 24 times the area of the Netherlands. With such potential to reduce carbon footprint, adopting geosynthetics in roadways is among the most promising uses of geosynthetics to address the world's sustainability needs.

References

[1] CIA (2020). The CIA World Factbook 2020-2021. Skyhorse Publishing, New York NY, USA.
[2] Zornberg, J.G. (2017). "Geosynthetics in Roadway Infrastructure." Procedia Engineering, Elsevier, Transportation Geotechnics and Geoecology, May, Vol. 189, pp. 298-306.
[3] Zornberg, J.G., Subramanian, S., Roodi, G.H., Yalcin, Y., and Kumar, V.V. (2024). "Sustainability Benefits of Adopting Geosynthetics in Roadway Design." International Journal of Geosynthetics and Ground Engineering, Springer (in press).


Kent P. von Maubeuge
Naue GmbH & Co. KG, Germany

SUSTAINABLE APPLICATIONS OF GEOSYNTHETICS IN HYDRAULIC ENGINEERING

Introduction

Due to climate change, humanity will face multiple and increasing challenges to keep safe and resilient living areas. The impact of climate change can be seen in the daily news. In July 2021, there were significant floods, e.g. in the cross-border region of Germany, Limburg (NL) and Belgium. Between April and August 2022, large parts of Europe were exposed to severe droughts. The levels of rivers like the Rhine were so low that this had tremendous impact to logistics by inland waterway vessels. The stagnation of the supply of sand/ gravel is a significant threat to construction. The good news is that applications with geosynthetics can significantly add value to limit the impacts of climate change. This can e.g. be realised with flood defence improvements, river bank restoration works, mitigation of eroding river beds and water containment systems for dry periods. With geosynthetic applications CO_2 emissions for structures can be reduced significantly. The hydraulic engineering sector was actually one of the earliest adopters of geosynthetics. One of the earliest (1970) and often quoted projects designed with geosynthetics is the Valcros Dam in France (Nancey et al., 1994).

Geosynthetics in hydraulic engineering

Geosynthetics are used in every major sector of civil engineering. One that has grown substantially in importance is hydraulic engineering. Flooding, coastal erosion, more frequent and intense storms, tsunami triggered flash-floods, expected sea-level rise, natural disaster prevention and other infrastructure concerns have prompted a call for solutions that are extremely durable, minimize a construction's carbon footprint, require less land disturbance, and are easier to implement. The scale of needs in hydraulic infrastructures also puts an emphasis on finding economical solutions without sacrificing safety and long-term performance. The performance, adaptable design options, and economics of geosynthetics have brought them every year more into hydraulic engineering projects. Geosynthetics provide filtration, sealing, protection, containment, separation, reinforcement, soil containment and erosion control solutions for canals, beaches, sea walls, waterside retaining structures, ports, levees, dams, offshore wind turbines, and much more. They replace, improve, or minimize the need for more costly, older engineering solutions. The full range of geosynthetics are utilized in these applications: geotextiles, geomembranes, geogrids, geosynthetic clay liners, drainage materials, geotextile containers, geosynthetic erosion products and others. Sand-filled nonwoven geotextile containers and tubes provide scour protection and stabilize beaches. Weighted materials such as sand ballasting mats and geosynthetic clay liners may be installed underwater. Geomembranes and geosynthetic clay liners (GCLs) protect water resources against pollution and seepage loss. Geogrids, geocomposites, and turf reinforcement mats strengthen levees. The range of work is broad and the beneficial impact of geosynthetics in these projects is substantial.

COASTAL PROTECTION

In the 1960´s practitioners in the USA and Europe started to use geotextiles for coastal protection works. A common application in coastal works is to use a nonwoven geotextile as a separation, filtration and erosion control layer. Geotextile underlay, topped with either sand/soil or stone, prevents wash out of the sediments below. This ensures that even if a hard storm affects the layer above, the geotextile prevents further erosion.
Sand-filled nonwoven geotextile bags, containers or tubes provide scour protection for wave-exposed structures (figure 1). They protect port walls, create artificial reefs and stabilize beaches. Of note, these highly durable bags, containers and tubes can be filled with site soils, making them efficient and cost effective.

In levees, geogrids and geotextiles strengthen the structures against flood event effects. They enable taller, more efficient construction and long-term strength against daily wave forces and surges. Geosynthetics are also used to prevent erosion of the core of a levee, which can occur in unprotected systems when water overtops and begins to carve out the levee's "dry" (downstream) side.

Whatever the application, nearly every coastal protection application must have a robustness. Seaside environments are challenging. Loads are frequent and fluctuating. There is considerable moisture to soften soils. Swift changes in weather and wave forces can occur and stress different points of a construction.

Decades of manufacturing experience and design, supply, and installation of geosynthetics give a detailed understanding of the challenges in hydraulic applications. These materials are designed to survive the difficult environments and provide long-term protection of coastal infrastructures.

CANALS

Commercial, agricultural, and recreational canals continue to be important economic drivers in many countries. A wide range of geosynthetic products, such as geotextiles, geomembranes, and geosynthetic clay liners (GCLs), help create more efficient waterways. These geosynthetics improve the long-term performance of canal systems by preventing bed and slope erosion and by decreasing significantly the risk of problematic sedimentation. The oldest canal installation carried out with a

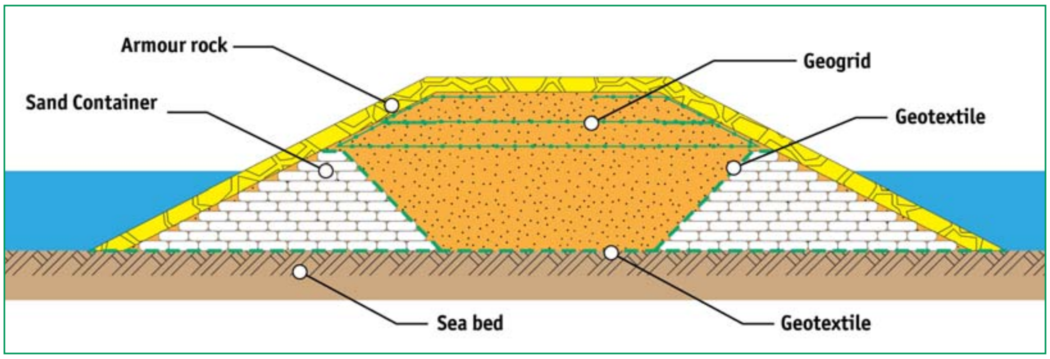


Figure 1 – Cross-section of a safe groyne with geosynthetics.

SUMMARY

Using geosynthetics, structures can be built more sustainably and economically than with traditional methods using mineral aggregate, clay, steel or concrete. Geosynthetics can replace or significantly reduce the use of these primary building materials. They also increase the service life of structures, like canals, levees or other hydraulic engineering applications. Compared to traditional construction methods, building with geosynthetics means in most cases a lower total energy demand, substantial reduction of CO_2 emissions and cost savings. Various applications and geosynthetic functions as well as the sustainability benefits are summarised in this article. It will be illustrated how responsible and sustainable solutions can be obtained by using geosynthetics. More important, the positive environmental impact of these solutions compared with traditional building methods are described. The contributions of geosynthetics to the construction of resilient structures as the big future challenge for climate change adaptation are outlined.

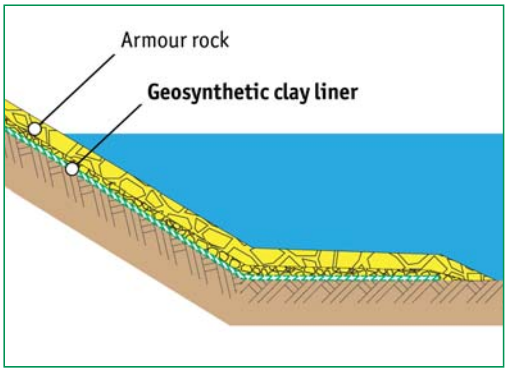


Figure 2 – Cross-section of a GCL lined waterway canal.

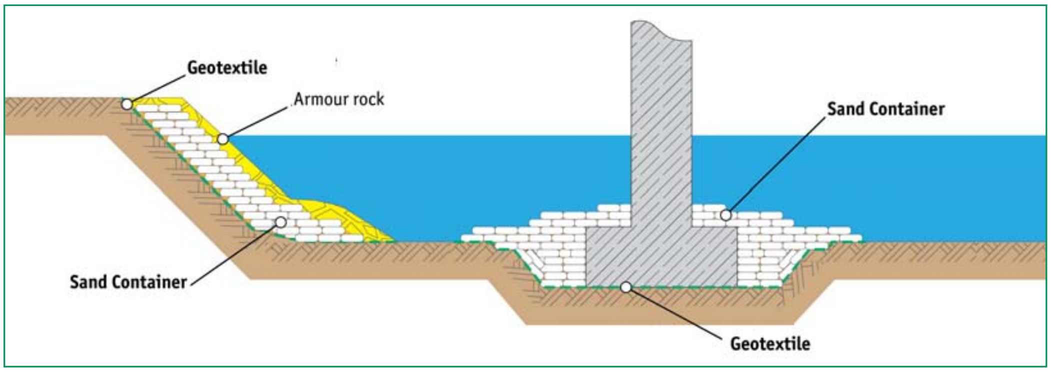


Figure 3 – Scour protection with geotextiles and sand filled geotextile containers in a river application.

nonwoven geotextile is a testament to the long-term durability and success of geosynthetics in erosion control applications. The Mittelland Canal, Germany, incorporated nonwoven geotextiles in 1967. In 2017, the project marked its 50th anniversary and excavated nonwoven geotextiles were tested and no degradation was recognized. Water quality in canals is preserved, water flows more dependably, and canals continue to operate as intended. When installed below permeable revetments (e.g., riprap) as a filter layer, needle-punched nonwoven geotextiles prevent erosion and soil displacement, even under high hydrodynamic loads. The high elongation capacity and robustness of the nonwoven geotextiles allow them to easily accommodate to irregular and soft subgrades.

Geotextiles are also used in protection applications with canals, such as to separate a barrier material (e.g., geomembrane) from a cover aggregate. When geotextiles are used this way, the canal lining system takes full advantage of the durability properties of the nonwoven geotextiles. The lining system is protected against damage during installation, which is crucial to ensuring its proper performance in service.

Barrier geosynthetics such as geosynthetic clay liners (GCLs) and geomembranes are used to improve canal performance (figure 2) in numerous applications. For irrigation canals, geosynthetic lining systems prevent seepage loss into soils. This improves the economics and sustainability of the irrigation system. The geosynthetic barrier also optimizes water flow in the canal network. Irrigation is conveyed more quickly and efficiently. For hydroelectric canal systems, water is delivered to the power generating stations more dependably and cleanly.

Commercial and recreational canals also benefit from the installation of geosynthetic lining systems. Geomembranes and GCL barriers can prevent sedimentation of waterways from high flow or from propellers stirring up the water along the bed. Where water levels are at an elevation higher than the natural groundwater level, the seal guards against seepage loss, thus keeping the canals open to safe navigation.

SCOUR PROTECTION

Flowing water presents significant challenges. Currents erode banks and stir up sediments. They can also scour out soils at the base of bridge piers. Beachfronts get washed out and infrastructure is weakened. For canals, channels, rivers, and waterfronts, numerous geosynthetics are used to mitigate the impact of moving water.

Sand-filled geotextile bags or containers are used to provide scour protection for offshore wind turbine footings, port walls, bridge pilings (figure 3), and other structures. Their filter stability and long-term durability resist the prolonged impact of wave forces and flowing water erosion. They are also an extremely efficient and economical solution, through enabling a greater re-use of local soils for filling the scour protection geotextile containers, sand bags, and tubes.

Where cavities have already occurred in a waterway due to scour, sand-filled containers can be installed to fill the space. The robust, needle-punched nonwoven geotextile material is durable against rough site conditions and prevents further scouring.

Barrier geosynthetics (geomembranes and GCLs) are also used to prevent the wash out of soils in flowing waterways. In irrigation, commercial and hydroelectric canals, geomembranes and geosynthetic clay liners improve water flow and prevent currents from eroding canal beds and slopes.

Sites that benefit from lining system protection against scour include dams, levees, canals, and many others.

Geosynthetic clay liners and geomembranes provide this sealing support. Depending on the force of water flow and site conditions, additional geosynthetic support such as a protection geotextile may be used.

HYDROELECTRIC POWER

Hydropower generates roughly 17% of the world's electricity and 70% of global renewable energy. Canals, dams, pumped storage stations, and other engineered structures are all part of the vast hydroelectric infrastructure. Geosynthetics play a strong role in the sector, particularly in rehabilitation of aging hydroelectric facilities and in decreasing the construction costs and long-term maintenance needs of new facilities.

For hydroelectric canal systems, which provide operational waters to generation stations or navigation ways around generation points, a variety of geosynthetics are used. Geomembranes can provide cleaner, swifter flow of hydroelectric water supplies, just as geosynthetic clay liners can.

Pumped storage systems are highly efficient means for balancing electrical grids. Water can be stored during non-peak times and released at peak into the hydroelectric generation system. In this way, strain on the system and the cost of responding to fluctuating electrical demands decreases. Geosynthetic barriers, such as geomembranes and GCLs, are used to provide storage security in these facilities to increase operational efficiency (figure 4).

With dams and power stations, geosynthetic reinforcement can be used to replace more conventional and significantly more expensive concrete retaining walls. For example, the use of a reinforced structure system for the wing walls of a hydropower station in Turkey saved 40% on the originally proposed concrete wall design. The use of geogrids and nonwoven geotextiles in the MSE system also replaced what would have required 700 trucks of special concrete pour.

Whether construction is new or a site is being rehabilitated, geosynthetics make hydroelectric power applications more economical and efficient. Waterways can be deepened, retaining walls can be built with significantly smaller carbon footprints, erosion can be removed from the system, stored water supplies can be more sustainable, and much more.

FLOOD PROTECTION

Geosynthetics provide easy-to-implement solutions for flood defenses, with project records extending back 40 years or more. When waters rise in a levee system, the integrity of the levee itself may be at risk if the water overtops. The "dry" (downstream) side of the embankment often lacks the engineering found at the expected interface of water and soil/structure. But if water reaches the other side of the levee, that embankment – often earthen – may develop rills. Erosive water might seep into the core of the levee, weakening it, and precipitate failure.

Geosynthetics resolve threats like this, often in ways that can be adapted easily to the local conditions. This flexibility in options is one of the great advantages in incorporating geosynthetics.
For flood protection designs, nonwoven geotextiles provide filter stability, drainage performance, and soil separation. They prevent clogging and guard against piping to maintain the integrity of a flood defense structure.

Geomembranes and geosynthetic clay liners (GCLs, also known as bentonite mats) provide long-term containment protection. They prevent seepage into the core of an embankment.

Multi-component GCLs (figure 5) provide a durable and uniform polyethylene coating on the material's woven side, creating an additional low permeability barrier for exceptional waterproofing. The special coating on a multi-component GCLs enhances root penetration protection into a levee system. GCLs provide efficient, long-term lining performance and strong protection in barrier applications. The polymeric coating on the series provides additional protection against desiccation and root encroachment as well as enhanced hydraulic barrier characteristics.

The thin profile of geosynthetic clay liners takes up considerably less space than conventional com-pacted clay. In a flood protection design, this can provide substantial savings, as far less soil may need to be removed to install the geosynthetic solution versus compacted clay. The GCL can be installed on site much more quickly than compacted clay, which requires timely placement and preparation. GCLs can also be delivered to site in far fewer truckloads than clay.

For earthen embankments and flood plains, erosion control materials give roots security and help retain soil in heavy precipitation. The labyrinth-like, three-dimensional matrix of the erosion control matting prevents the sliding and washing out of the soil and cover layer while facilitating rapid vegetation growth. The reinforcing character of the matting prevents erosion under heavy rains and water flows.

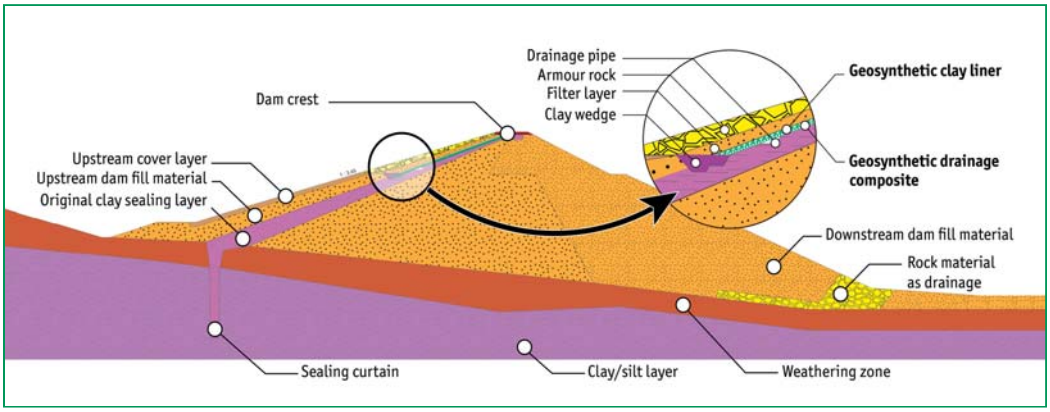


Figure 4 – Cross-section of a water pump storage station sealed with a GCL.

Reinforcement geosynthetics are used as well. In poor soil conditions or on steeper slopes, geogrids can be used to further ensure slope stability. Composite geogrids (e.g. nonwoven embedded between the geogrid reinforcing bars) are also an option. This unique construction of a geosynthetic provides separation, drainage, and filtration along with the expected reinforcement.
Overflow protection for levees can increase the cost of design, and for this reason many levee systems have historically not had overflow defenses designed into them. Geosynthetics provide cost-savings through various design, construction, and performance means to reduce costs while enhancing safety.

A levee segment is defined by a specific function and a defined cross-section with elementary structures or components. These components have specific and individual functions and should maintain the integrity of the levee. A German levee is divided in three zones (figure 6):

– Barrier zone
– Stability zone
– Defense zone

One main advantage of a zoned levee over a homogeneous soil levee is the better sealing effect. Here, geosynthetic clay liners with very low permeability are generally an ideal solution for the up-stream barrier zone. This ensures that the seepage line in the levee body is lower and less seepage water occurs.

An important component of a river levee is also the levee defense road. This should be located immediately behind the landside levee embankment to provide access to any portion of the levee route during a flood event. It is often constructed slightly elevated on a berm and must be capable of being travelled by heavy motor vehicles during a flood and therefore must be adequately protected against softening or settlement (typically with geotextiles and geogrids). It is usually constructed over the foot drain as a paved road.

There are many possible solutions with geosynthetic materials for flood defences. Levees are traditionally constructed with a 0.5 m to 1 m thick clay layer that functions as barrier. A bentonite mat (geosynthetic clay liner, GCL) is more and more used to replace such a clay layer.

The benefits for this application can be summarisedas follows:

– Saving natural resources (no clay required), and stimulating the use of locally available soils.
– Less sensitive to dry/wet cycles, so better resistant to periods of extreme drought which are expected due to climate change.
– Lower transportation costs and therefore less CO_2 emissions.
– Faster installation and reduction of the overall construction time.

At the location of Neer (Limburg, The Netherlands), the Water Authority Limburg improved the foreshore of the levee using a bentonite mat (GCL) as a measure against piping. The GCL panels were laid in connection with a natural clay top layer to lengthen the necessary seepage path. A second levee improvement project is done in Beesel, where GCLs are applied on the crest and the slopes, replacing the full clay cover layer on the levee (figure 7). This project is unique for levee building techniques in The Netherlands, as it is the first time ever that GCLs are applied directly at the core of the flood defence. The pilot project is closely followed by several other regional water authorities and the HWBP (Hoogwater Beschermingsprogramma – Flood Protection Program).

The experiences will give input and learning points to other flood defense projects in the future. Another important application in flood defense systems (levees) is the use of nonwoven filter geotextiles under stone revetments. The nonwoven replaces the use of finer gravel and sand interlayers which otherwise are needed to build up a natural filter layer to the very coarse rock layer. In case of limited space, the slope of levees can additionally be steepened by using geogrid reinforced soil constructions

RESPONDING TO CLIMATE CHANGE - CLIMATE ADAPTATION AND MITIGATION

Climate adaptation means anticipating the negative impacts of climate change and taking appropriate action to prevent further damage. There are two basic principles to respond on climate change: mitigation and adaptation.

While mitigation aims to limit negative impacts by reducing greenhouse gases, climate adaptation aims to adapt life to changing environmental conditions.

Before humans began to influence and significantly alter climate, they adapted to living in extremely dry regions, surviving in ice deserts, river flood plains or low-lying delta areas. Humans have developed strategies to adapt to these inhospitable conditions.

Today's population densities and resource demands

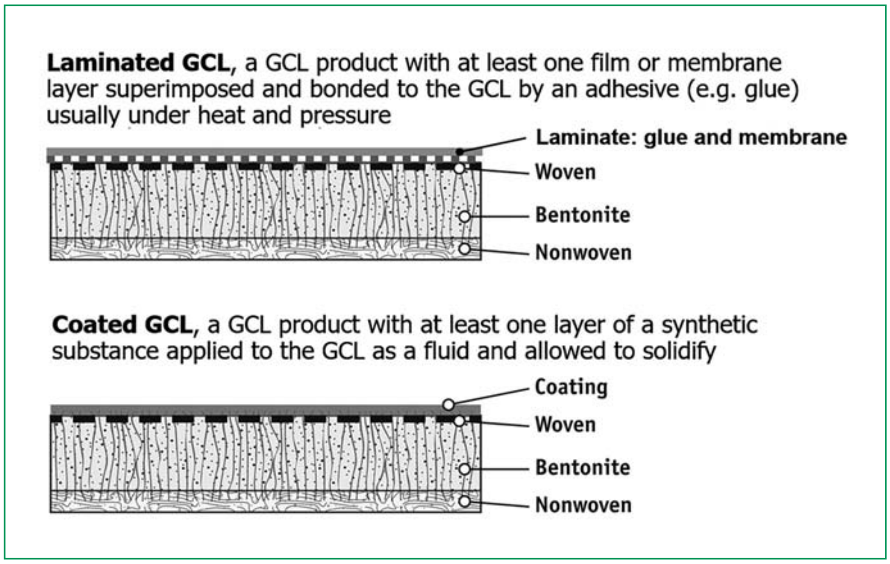


Figure 5 – Cross-section of a laminated and coated multi-component GCL (von Maubeuge et al., 2022)

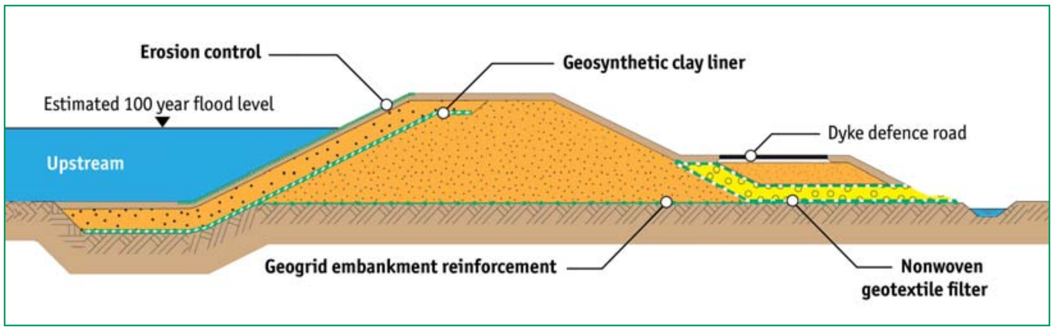
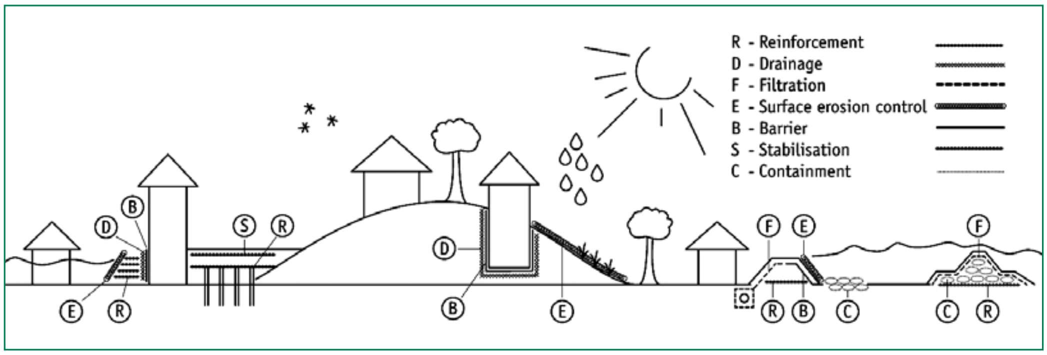


Figure 6 – Cross-section of a levee for flood protection with geosynthetics.

Figure 7 – Levee improvement with installation of a GCL on the crests and slopes of the flood defence to replace the 1 m thick clay barrier and stimulating re-use of local soil for the levee core (Beesel, The Netherlands).

Figure 8 – Cross-section illustration of climate adaptation with multiple options for geosynthetic applications.



make adaptation by evasion less and less feasible. Concepts that enable and secure life in all parts of the world by increasing resilience and adaptation to new conditions are needed.

Well-planned and early adaptation measures using geosynthetics save money, resources and lives later.

In terms of mitigation, geosynthetics in retaining structures reduce CO_2 release by approx. 70 % in comparison with traditional methods like concrete walls or steel sheet piles (GSI, 2019). This means that alternative and smarter designs with geosynthetics can reduce global warming effects. At the same time, such structures are robust, economical and ecological. For climate adaptation geosynthetics can be used in multiple ways (figure 8). Examples are embankment reinforcement, stabilizing roads, structure waterproofing, slopes and flood defences. The hinterland can be protected from flooding by a double levee system.

CO_2 EMISSIONS AND LIFE CYCLE ASSESSMENT (LCA)

By using geosynthetics, CO_2 emissions can strongly be decreased. In figure 9, a CO_2 emission comparison of a 36,000 m3 large barrier application with a 50 cm thick traditional compacted clay layer and a technically equivalent 10 mm thick bentonite mat is shown. It turns out that the use of the bentonite mat is ecologically much more favourable than the use of traditional compacted clay layers, with at least identical or even improved effectiveness. The enormous soil masses of a traditional compacted clay liner have to be trans-ported. This requires a lot of energy, mostly in the form of diesel fuel, which of course emits huge amounts of CO_2 (in this project 9.9 kg/m²). The total CO_2 emissions (figure 9) of the GCL are with 4.0 kg/m² significantly lower than the values of the compacted clay liner (9.9 kg/m² – a factor of 2.5 higher).

In principle, it is advisable to carry out an overall assessment and this is possible with a life cycle assessment (LCA). For the (near) future LCA will play an increasingly important role in the design considerations. The method of "ecological balancing" emerged from the balancing methodology following Stolz et al. (2019) and has been currently further developed. An important driver for the implementation of comparative LCA is the international and EU-internal emission rights trading with greenhouse gases.

Only the value of such CO_2 certificates makes it clear how important the intelligent selection of materials and construction methods can be for the environment. It would therefore be important in the EU to implement the issue of comparative LCA more strongly. The goal must be to introduce an assessment in construction measures that allows a comparison of building systems.

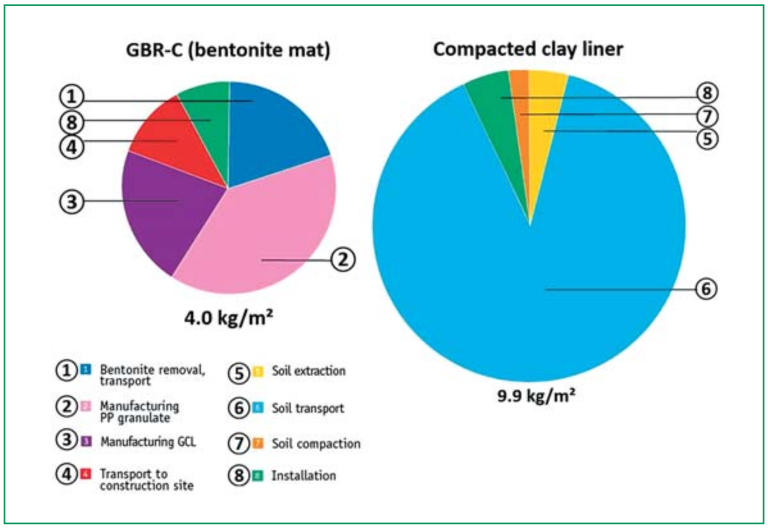


Figure 9 – Comparison of a bentonite mat (left) with a traditional compacted clay layer of 0.5 m (right) in terms of CO_2 emissions from a 36,000 m² barrier project (von Maubeuge et al., 2021).

CONCLUSIONS

The use of the economic and ecological "geosynthetic" construction material has become widespread in many areas of geotechnical engineering in the past decades. Geotextiles, geogrids, geosynthetic sealing and drainage systems allow technically accurate, low-cost, alternative solutions and offer advantages like reduced environmental impact.

Geosynthetics are used in a wide variety of areas. They are used in many fields in hydraulic engineering. For each application area, a geosynthetic developed for the individual requirements has to be selected properly. A geosynthetic used in offshore applications has to meet different requirements than a geosynthetic used in levee construction or one as a canal liner.

Geosynthetics are multifunctional with functions such as separation, reinforcement, protection, filtration, drainage, sealing (barrier), soil encapsulation. It is also possible to combine different geosynthetics with each other in high-level engineered structures to ensure safer and longlasting structures. The advantages of geosynthetics can be summarised as follows:

- Reliability: high-quality control standards, lifetime verification and multiple proven project applications.
- Ecology: significantly lower CO_2 emissions, supporting climate goals, lower energy consumption, reduction of transport kilometres.
- Sustainability: limit the use of resources (construction materials, energy demand), less noise impact.
- Cost-effectiveness: reduced building cost compared to traditional methods, longer service life, less maintenance.
- Easiness: easy to handle and install on project sites, saving time in the construction process.
- Resilience: improved structural behaviour with the ability to respond, absorb, adapt or recover from extreme load cases caused by climate changes.
- Safety: increased serviceability and protection at e.g. or levees or other applications.

It can be concluded that the development of geosynthetics is one of the most significant developments in geotechnical engineering, especially when looking at the positive environmental impact.

Due to climate change, humanity will face multiple and increasing challenges to keep safe and resilient living areas. Applications with geosynthetics can add significant value to limit the impacts of climate change.

References

– Geosynthetics Research Institute, (2019), GSI White paper #41, Relative Sustainability (i.e., Embodied Carbon) Calculations With Respect to Applications Using Traditional Materials Versus Geosynthetics, https://geosyntheticinstitute.org/papers/paper41.pdf.
– Maubeuge von, K.P., Stoyle, J. (2021). The ISO design guide for geosynthetic barriers and the use for safe and economic barrier solutions", 11th Int. Conference on Geotechnique, Construction Materials & Environment, Kyoto, Japan, 3-5 November 2021, ISBN: 978-4-909106063 C3051, page 428.
– Maubeuge von, K.P. von and Fong, J. (2022). Multi-component Geosynthetic clay liner improves the performance of landfill barriers. 11th Asia-Pacific Landfill Symposium (APLAS), Bangkok, Thailand.
– Nancey, A., Delmas, P., Faure, Y. H., Farkouh, B. (1994), Long Term Behaviour of a Geotextile as a Filter in a 24-Year Old Earth Dam. ICG 5, Singapore.
– Stolz, P, Frischknecht, R. (2019), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction materials.
– www.eagm.eu/_files/ugd/3459562d895800c5b6409892cdf7d847bd6ab4.pdf.


Wim Voskamp
Voskamp Consultancy

SUSTAINABLE USE OF GEOSYNTHETICS IN THE NETHERLANDS

Sustainability benefits of geosynthetics

The use of traditional building materials such as concrete, steel, clay or sand makes a major contribution to CO_2 emissions. The energy consumption related to their production and processing is often high. Geosynthetics can make a major contribution to reducing emissions and energy consumption, since the volumes of the traditional building materials are greatly reduced with the use of geosynthetics.

In recent years this has been demonstrated by several large Life Cycle Analysis projects in which traditional construction methods were compared to construction methods using geosynthetics. The results of these studies are summarized in Tables 1, 2 and 3.

The GRI-24 Conference on Sustainability listed the average embodied carbon savings in 25 analysed applications in the USA. An overall average of 65 % reduction in carbon footprint using geosynthetic related alternatives was realized (Geosynthetics Research Institute, 2019).

Depending on the application it may be concluded that the use of geosynthetics reduces the carbon footprint with 30 – 89 % compared to the use of traditional civil engineering materials as concrete, steel, gravel etc. The savings in energy vary from 5 – 85 %, heavily dependent on the transport distance and the volume of the building materials.

Figure 1 – 6 and 9 give an overview of some of the projects in the Netherlands where geosynthetics were used and which resulted in considerable savings in CO_2-emissions, used energy and in a reduction of used primary raw materials.

Sustainability goals

Through legislation, the goals of the UN Climate Change Conference (COP21) in Paris have been converted into goals at European level and country level. The goals for the Ministry of Infrastructure and Water Management and Rijkswaterstaat are derived from the goal for the Netherlands. Rijkswaterstaat (RWS) is, among other things, the public works implementation agency of this ministry and is responsible for the construction of all projects at national level. In addition, there are the provinces and large cities, each of which can also be owners of large projects. They follow RWS with regard to the sustainability goals.

EUROPEAN UNION

The world-wide target for reduction in the world temperature was set at the UN Climate Change Conference (COP21) in Paris as:

"The increase of global temperature must be well below 2° C above pre-industrial levels".
And to pursue efforts "to limit the temperature

Table 1 - Case study results from WRAP report (WRAP, Waste & Resources Action Programme, 2010)

Case History	*Traditional Approach CO_2 Footprint (tons)*	*Geosynthetic Approach CO_2 Footprint (tons)*
#1 Slope Stability	157	21
#2 Bridge Approach	500	346
#3 Crib Wall	35	11
#4 Sheet Piling Wall	433	69
#5 Concrete Wall	107	20

Table 2 - Savings in energy consumption and CO_2 emissions compared with traditional structures made with traditional construction methods, (Stuecki M, 2011)

Savings compared to structures made with traditional construction methods

Application	*Energy consumption*	*CO_2 emissions*
Separation material in a road construction	85%	89%
Road foundation reinforcement	5-10%	32%
Drainage layer	56%	67%
Retaining wall	85%	75%

Table 3 - Case studies from GRI-24 Conference (Geosynthetics Research Institute, 2019)

Application Area	*No. Cases Described*	*Average Carbon Savings*
Walls	6	69%
Embankments and Slopes	4	65%
Armoring	4	76%
Landfill Covers	3	75%
Landfill Liners	2	30%
Retention	3	61%
Drainage Pipe	3	40%
Totals	**25**	**65%**

Figure 1 & 2 – Reinforced slope A24, Blankenburg connection, Rotterdam. Steep slopes, longer embankment resulting in considerable saving in concrete.

SUMMARY

The rise in global temperature and consequent climate change require a reduction in greenhouse gas emissions by reducing the use of raw materials and fossil fuels. Sustainability, both in the production of geosynthetics and in their use are important.

The major advantage of using geosynthetics compared to traditional building materials is the reduction in CO_2 emissions because less primary raw materials such as concrete, sand, gravel are used. The reduction in CO_2-emissions varies from 30 – 89%. In addition, there is also a large reduction of the required energy compared to the traditional construction methods. This can be up to 85% depending on the chosen technology.

Figure 3 – Road base reinforcement, Onderdendam, Bedumerweg, thinner foundation layer, less fill material, less transport, extended service life.

Figure 4 – Pile-supported geosynthetic mattress, Leiden A4 Hofvliet, settlement free construction method, extended service life, less fill and transport.

Figure 5 – EPS Lightweight fill, Ramp to viaduct over A4 near Schiedam, settlement free construction method, extended service life, less material and transport.

increase to 1,5° C above pre-industrial levels" (UN, 2015).

The European Climate Law writes into law the goal set out in the European Green Deal for Europe's economy and society to become climate-neutral by 2050. Climate neutral means achieving net zero greenhouse gas emissions for EU countries as a whole, mainly by cutting emissions, investing in green technologies and protecting the natural environment (European Climate Law, 2024).

THE NETHERLANDS

By 2030, the Netherlands must emit 55% less greenhouse gases compared to 1990. The aim is even a 60% reduction. The Netherlands want to be climate neutral by 2050. This means that greenhouse gas emissions in 2050 will not be higher than what is stored, so the net emissions are zero (Rijksoverheid, 2024).

MINISTRY OF INFRASTRUCTURE AND WATER MANAGEMENT

The Ministry of Infrastructure and Water Management has the ambition to make the purchasing chain completely climate neutral and to work circularly by 2030 at the latest. This would mean no CO_2 emissions as result of the infrastructure project, high-quality reuse of all materials and halving the use of primary raw materials. To achieve this, it focuses on reducing its own CO_2 emissions and uses its influence as a client for the large infrastructure projects (Ministerie van I en W, 2024).

Rijkswaterstaat is the Public Works Implementation Agency. All governmental infrastructural construction is handled by them. It is one of the most sustainable public procurers in the Netherlands This is mainly due to the use of the Environmental Cost Indicator (Milieu Kosten Indicator MKI) in tenders for new infrastructural works (Rijkswaterstaat, 2023). The Environmental Cost Indicator (MKI) is used to calculate the environ-

Figure 6 – Road under groundwater level, N206, Katwijk, a geomembrane with protection layer is applied instead of a concrete wall and foundation layer, resulting in less primary raw materials, large savings on concrete and no pile foundation.

mental effects of civil engineering works. The lower the value, the lower the environmental impact and the greater the contribution to CO_2 reduction.

Rijkswaterstaat wants to work circularly by 2030. This means: working without waste and reusing raw materials. They therefore strive for high-quality use and reuse of materials. They are also increasingly using sustainably produced materials in infrastructure projects (Rijkswaterstaat, 2024).

Actions taken to achieve the goals

TRANSITION PATHS

Rijkswaterstaat has defined transition paths as a roadmap to achieve a climate-neutral and circular infrastructure in 2030. It sets out various intermediate goals and steps that provide a joint guideline for authorities and market parties to realize this vision. They indicate where the greatest reduction can be achieved.
The roadmaps indicate the direction and pace of the transition. This makes it clear to the market what the authorities require from the sector and market parties can tailor their revenue models and investments accordingly. There are roadmaps for the five most important applications:

- Structures
- Road pavement
- Coastal works and river works
- Sustainable building site organization and logistics
- Railways

To take big steps, RWS works closely together with branch organisations, institutes and other market parties and reached agreements on:

- to develop and apply circular biobased asphalt;
- to reduce CO_2 emissions in concrete and to reach a high level of recycling of concrete;
- to reduce emissions and energy consumption in the steel construction industry;
- to develop emission-free construction sites with attention to construction hubs, use of emission-free tools and digitalization.

ENVIRONMENTAL COST INDICATOR

As part of the best price-quality ratio (BPKV) tender-evaluation, an emission target is nowadays fixed as base level in the tender documents for all medium and large size public infrastructural projects. For all designs proposed by contractors during tendering a Life Cycle Analysis must be made and based on the Environmental Cost Indicator (ECI, or in Dutch: Milieu Kosten Indicator MKI), the shadow price is calculated. The shadow price is an award criterion in the best price-quality ratio for tenders, used as fictitious discount on tender prices. (Rijkswaterstaat, 2023). The steps that have to be taken are (Molenaar, 2024):

- Perform a Life Cycle Analysis (LCA) for the entire project. Including all phases like production of materials, transport, construction and removal.
- Calculate the Environmental Cost Indicator. A computer program (Dubocalc) has been developed by RWS to calculate this ECI (MKI) value. The ECI (MKI) value is part of the best price-quality ratio evaluation of tenders.
- Set limits for the ECI / MKI values for the project.
- Determine the fictitious discount of the tender price per project based on the relative ECI (MKI) value. The fictitious discount of the tender price per project is set. In the example of fig. 7, 8 the estimated costs of a project is set at Euro 10 mio. The fictitious quality value is set as 60% of the project costs. MKI or ECI value is 35% of the fictitious quality value: 0,35 x 6 = 2,1 mio Euro. This maximum fictitious discount can be achieved for the lower limit of MKI value. For the upper limit the discount is 0. The fictitious discount for the tender price interpolated between these values as shown in figure 8.
- Award the contract based on the discounted tender prices.

In this way designs with low emissions and reduced quantities of primary raw materials are promoted. This gives a strong boost in the use of geosynthetics.

LIFE-EXTENDING DESIGNS

The design of roads and structures can have considerable effect on the ECI (MKI) value. In case the service life of for example a road can be lengthened it automatically results in an average reduction of emissions and energy per year.

Also in case a structure does not need considerable amounts of primary raw materials it means a saving. Application of geosynthetics in a structure can e.g. replace a concrete wall, or steeper slopes can be built, resulting in the use of less fill material. So the directly related emissions and energy consumption will reduce and the used energy as result of transport and installation will also reduce. Examples are reinforced embankments, reinforced walls, road base reinforcement, etc.

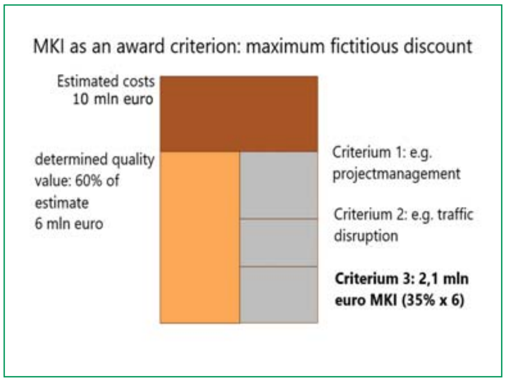


Figure 7 – Calculation of fictitious discount based on ECI. (Ref. Rijkwaterstaat NL)

CIRCULARITY IN THE USE OF MATERIALS AND COMPONENTS

Development projects have been initiated for recycling of concrete, steel and asphalt. Recycled concrete is often used as rubble granulate in foundations of roads. The objective is to use this granulate again as granulate in new concrete. During the design of new projects, reuse of primary raw materials from nearby projects that are being demolished must be taken into account. At the moment, geosynthetics are being developed made from recycled polymers. Some of them are already available: vertical drains, some woven and nonwovens.

The re-use of components is also important in circularity design. Not only steel components or concrete beams can be re-used. Also geosynthetics could be re-used after they have been built in and served for many years. Careful removal is of course important to prevent damage and the removed products have to be examined. The quality has to be evaluated and the properties for future use must be set after examination. A probably easier way is to re-cycle the geosynthetics after removal. Careful evaluation must be done in case of reinforcement material but re-use of nonwoven as separation layer does not require special measures.

Effect of use ECI / MKI quality criterion on design of civil engineering projects

During the design of civil engineering projects, various criteria must be considered to ensure functionality, safety, and compliance with regulations. The main design criteria are:

- Functional requirements
- Technical feasibility
- Structural safety
- Durability
- Compliance with laws and regulations
- Economic feasibility

All these criteria are taken into account during the design.

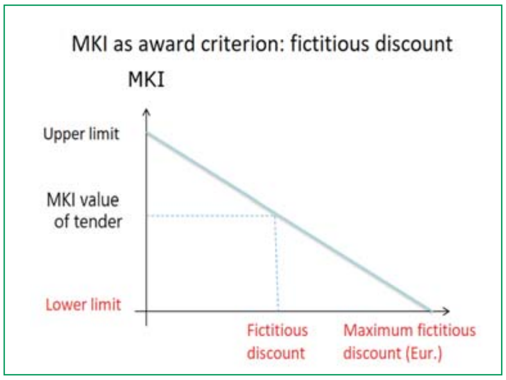


Figure 8 – Calculation of fictitious discount with linear interpolation between limits. (Ref. Rijkwaterstaat NL)

With the increasing importance of the environmental impact of a new project, the design of civil engineering projects changes. The fact that the Environmental Cost Indicator (MKI indicator) is now a criterion in the best price-quality ratio (BPKV) tender-evaluation makes reduction of the emissions and energy used an important design aspect. It can have a direct effect on the award of a tender as, at present, the fictitious discount for new structures can reach 21% of the standard price of the project. This means that there is now a new focus during design. Not only the technical and economical aspects are important but also the reduction of environmental costs (through the LCA and ECI / MKI values) plays an important role by its effect on awarding of tenders in the BPKV analysis.

Figure 9 – Levee reinforcement Beesel, Water Authority Limburg, Geosynthetic Clay Liner installed on slope and top of dike replacing 1 m thick clay layer, saving in primary raw materials, CO_2 emissions and energy.

Use of recycled polymers for geosynthetics

Geosynthetics are made of synthetic polymers, which are supplied by the chemical industry. Macro molecules are made by means of a polymerisation process in an extruder. The polymer properties such as molecular weight, degree of crystallinity, melt flow index, viscosity, melting temperature etc. are important properties for the product that is made. Any contamination of the polymer compound should be eliminated to prevent cutting of the yarn during the extrusion through the very small opening or clogging in a flat-die manufacturing process of a geomembranes.

In case recycled polymers are used in the production process, they must fulfil stringent requirements on the properties, no large variations are allowed. This results in strict requirements in the recycling process. It is not necessary to use re-cycled polymer of earlier used geosynthetics. Recycled polymers from other sources can also be used, as long as the stringent quality requirements are fulfilled. This gives an opportunity to start with the use of recycled polymer for geosynthetics in the short term. Also if necessary a mix of virgin and recycled polymers can be used in case that is required. At the moment of writing there are already some products available in the market which are partly or entirely made of recycled polymers.

Sustainability in the production of geosynthetics

Significant reductions in CO_2 emissions and energy use can be achieved during the production of geosynthetics. Environmental protection measures that can be taken (Ramsey, 2022):

- The use of packaging material can be greatly reduced.
- The transport of semi-finished products in the factory and of finished products to storage and to the end-user can be organized as efficiently as possible.
- Generation of energy by means of solar panels on the roofs of factory halls leads to the use of sustainable energy.
- Extrusion of polymeric material is done at high temperature. After this, the formed geosynthetic material must be cooled. In this process, heat can be recovered.
- Waste material that results from the production process, such as cut off sides of polymer sheets, short rolls etc. are shredded and are fed into the production process again.
- Re-use of end-of-service-life material after purification of contaminants as a separate raw material stream.
- Develop new production methods that allow the use of other post-industrial polymer waste and post-consumer polymer waste material.

References

- European Climate Law. (2024). Retrieved april 17, 2024, from https://climate.ec.europa.eu/eu-action/european-climate-law_en: https://climate.ec.europa.eu/eu-action/european-climate-law_en
- Geosynthetics Research Institute. (2019). White paper #41 Sustainability.
- Minister van Infrastructuur en Waterstaat. (2024). Brief aan Tweede Kamer, 31-5-2024, Toelichting circulair klimaatbeleid. Retrieved from https://open.overheid.nl/documenten/dpcb8a342f446cf88a986ee839a5918826f9ee5764/pdf.
- Ministerie van I en W. (2024). certificatie voor de CO_2 prestatieladder. Retrieved from www.rijksoverheid.nl/ministeries/ministerie-van-infrastructuur-en-waterstaat/organisatie-ienw/certificatie-voor-de-co2-prestatieladder
- Molenaar, K. (2024). MKI als sturingsmiddel. Retrieved april 2024, from https://betonhuis.nl/system/files/2021-06/webinar-2-betonakkoord-rws-mki-als-sturingsmiddel.pdf
- Ramsey, B. (2022). Geosynthetics and sustainability: How is our industry doing? Geosynthetics Magazine, p. 4. April 1, 2024. Retrieved from: https://geosyntheticsmagazine.com/category/features
- Rijksoverheid. (2024). Voortgang climatedoelen. Retrieved April 17, 2024, from www.rijksoverheid.nl/onderwerpen/klimaatverandering/voortgang-klimaatdoelen
- Rijkswaterstaat. (2023). Handleiding aanbesteden met MKI. Retrieved May 10, 2024, from: www.pianoo.nl/sites/default/files/media/documents/2024-02/bijlage_d2_handleiding_aanbesteden_met_mki-dec2023.pdf
- Rijkswaterstaat. (2024). Circulaire economie. Retrieved April 17, 2024, from: https://www.rijkswaterstaat.nl/leefomgeving/duurzaam-werken/circulaire-economie
- Stuecki M, e. a. (2011). Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials. Uster: ESU-services Ltd.
- UN (2015). Paris Agreement. Retrieved April 18, 2024, from https://www.un.org/en/climate-change/ paris-agreement
- WRAP, Waste & Resources Action Programme. (2010). Geosystems Report, Sustainable Geosystems in Civil Engineering Applications. London: WRAP.

Photos are published with agreement of:
Photo 1, 2, 3, 4: Joosten Groep bv
Photo 5: Infra Delft bv
Photo 6: Cofra bv
Photo 9: Naue

Amir Shahkolahi
National Technical Manager,
Global Synthetics, Australia

Jonathan Shamrock
Technical Director –
Landfill Engineering & Geosynthetics,
Tonkin and Taylor, New Zealand

Jabulile Msiza
Director, HOD – Waste Department,
Jones & Wagener, South Africa

SUSTAINABLE USE OF GEOSYNTHETICS IN LANDFILL APPLICATIONS

Introduction

Geosynthetics are extensively used in the design of landfill base and cover liner systems and other waste management facilities. This includes: geogrids to reinforce slopes to reduce the landfill footprint, reinforce cover soils above geomembranes, control differential settlements, provide a bridging layer for piggy-back liners above older facilities; geonets and geocomposite drains for in-plane drainage; geomembranes, which are impermeable sheets of polymeric materials that can be used as a barrier to liquids, gases and/or vapours; geosynthetic clay liners (GCLs), which are composite materials consisting of bentonite and geosynthetics that can be used as an infiltration/hydraulic barrier; geopipes to facilitate collection and rapid drainage of the leachate (water seeping through the waste) to a sump and removal system; and geotextiles to be used for filtration between waste and drainage layers or as a cushion layer to protect the geomembrane from puncturing (Koerner, 2012).

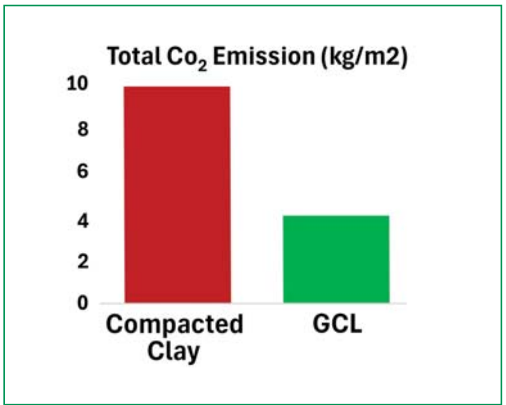


Figure 1 – Compacted Clay Liner (CCL - red) vs Geosynthetic Clay Liner (GCL - green).

Landfill sustainability strives to reduce emissions, not only during construction, but also during operation, closure and aftercare. As such, sustainable landfilling has two main components:
(1) Reduction in carbon emission and energy consumption during construction, and
(2) Reduction in long-term emissions and avoiding any harm to future generations (long-term performance).

This article provides a short summary of how geosynthetics can provide sustainability to a landfill during construction, operation, closure and aftercare (Shahkolahi, 2023).

Geosynthetic Clay Liners (GCLs)

CO_2 emission during landfill construction can be considerably reduced by using geosynthetics instead of traditional earthern materials. There are sites where the geology is such that material suitable for use in the barrier system is not available opening up borrow areas and stripping natural resources where an alternative equivalent can be used is also not sustainable. For example, using GCLs can provide a significant reduction in CO_2 emission compared to 500 mm thick Compacted Clay Liner (CCL). The transportation of soil to form a compacted clay liner requires a lot of energy (e.g. fuel), which produces significant quantities of CO_2. Figure 1 shows a comparison of CO_2 emissions between a GCL and 500mm of compacted clay to cover the same area (Von Maubeuge et al., 2018). Adding to that is the amount of water, energy and labour needed for preparation, placement and compaction of clay to provide suitable quality and performance (figure 2).

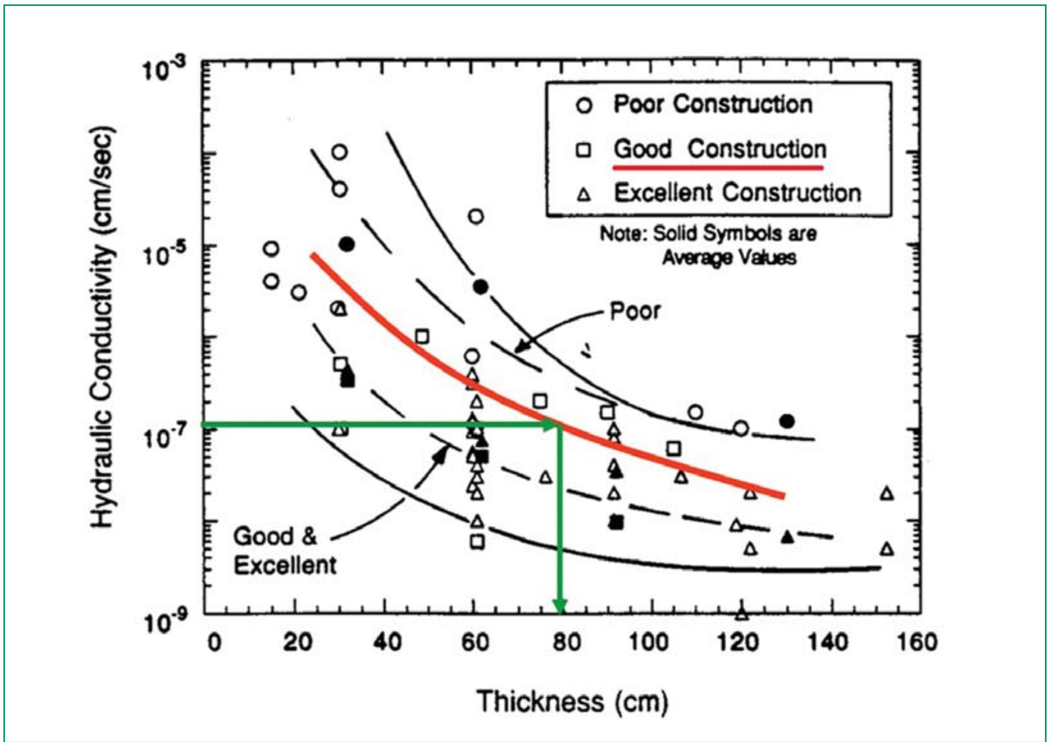


Figure 2 – Performance of Compacted Clay Liner as function of thickness (Benson and Daniel, 1994).

As a long-term barrier, a GCL is also less permeable than a CCL and also more compatible with differential settlements. Furthermore, field monitoring has shown an increase in CCL permeability over time due to natural soil processes compared to relatively stable performance from a GCL (Von Maubeuge, 2018). In addition, the needle-punching and thermal locking of GCLs can provide higher internal peak shear strength compared to a CCL. In recent years, multicomponent GCLs (GCLs with additional polymeric coating or film) have enabled further long-term benefits such as a barrier to root penetration and eliminating downslope erosion and desiccation and cation exchange protection. This material can also provide additional sustainability in the design and construction of landfills such as reduction in the required capping layer thickness which provides extra saving in the capping material and extra reduction in carbon footprint, as well as extra landfill space.

Geosynthetic Composite Drains (GCDs)

Geosynthetic composite drains such as geonet composites, cuspated drain composites, and multi-linear drainage composites are now very popular as a sustainable replacement for drainage

SUMMARY

Construction of a sustainable landfill includes reduction in carbon emission and energy consumption during construction as well as reduction in long-term emissions during operation, closure and aftercare, and avoiding any harm to future generations. Geosynthetics can provide sustainable alternative solutions to traditional construction methods which leads to reduction in using natural resources, construction costs, and transportation. Reducing transportation will not only reduce the related CO_2 emission (due to the fuel consumption), but also reduce the microplastic production, as vehicle tyres are the main source of producing microplastics (Boucher and Friot, 2017). Geosynthetics can also increase the long-term performance and durability of the leachate and gas collection systems. Landfills should not be built based on the cost only but consider currently available best practices for protecting future generations too.

gravel in landfill bases, slopes and caps for leachate, infiltration and gas collection. They offer a manufactured alternative to a thicker component without the disadvantages of moving high volumes of quarried rock materials and thereby reduce the extensive transportation costs and emissions. For instance, approximately 300 truckloads of gravel would be required to cover 10,000 m· with a 30 cm thick drainage layer. Only two truckloads of a drainage geocomposite would be required to cover the same area. The factors such as pre-controlled quality, easier, quicker, safer and low-cost installation, no use of natural resources, reduction in transportation energy and related CO_2 emission, durability, providing more air space, and equivalent or better performance under the site conditions than the granular layer, have made these products a cost-effective sustainable alternative to traditional methods. The greenhouse gas emissions of a drainage geosynthetic solution can be 50-90% lower than traditional solutions due to the significant reduction in the material requirement and related transportation emissions and the quicker and easier installation. For the same reasons, the emission of harmful nitrogen oxides (NOx – mostly from diesel engines) can be reduced by 70-95% (Heritage and Shercliff, 2020).

Flow rates from leachate collection systems of 287 single and composite lined landfill cells monitored for up to 10-years in a study completed for the US EPA, (Koerner, 2000) has shown that a geomembrane/GCL (GM/GCL) composite liner system outperforms the standard GM/CCL composite liner system in all cases and at every life cycle stage, and a geosynthetic double liner with a geosynthetic leachate collection system (geonet (GN)) outperforms the same system with sand as a leachate collection system in all stages including initial life, active life and post-closure (Figure 3).

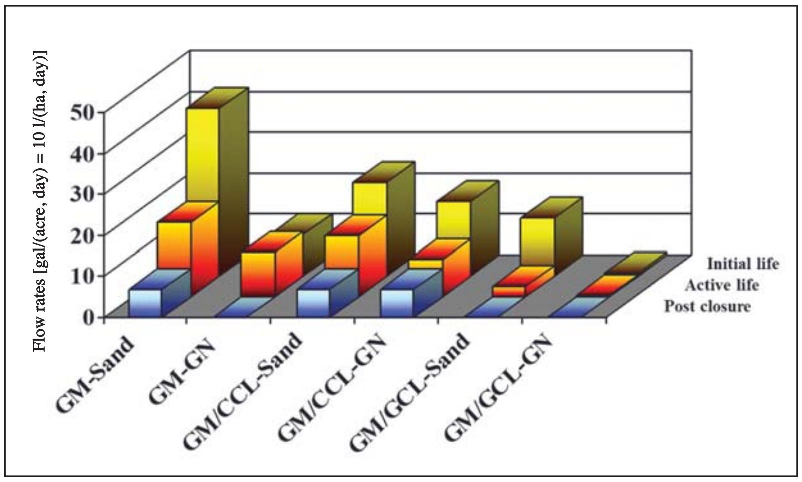


Figure 3 – Performance of different geosynthetics systems (after Koerner, 2000) with:
GM = geomembrane
GN = geonet (drainage)
CCL = compacted clay liner (natural clay)
GCL = geosynthetic clay liner.

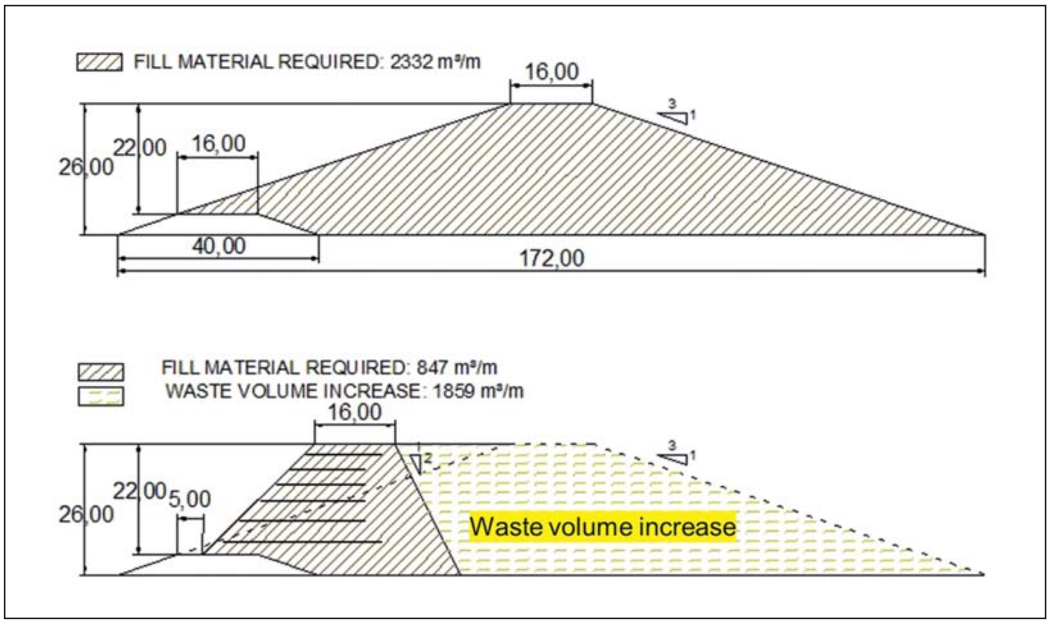


Figure 4 – Sustainability of reinforced landfill berms (Cazzuffi & Recalcati, 2021).

Protection Geotextile

Heavy nonwoven geotextiles are becoming common practice for geomembrane protection due to their lower costs, reduction in carbon emission related to transportation, landfill air space savings, speed of installation, and a lower risk of installation damage compared to traditional mineral protection layers. For applications where single geotextiles may not be sufficient to protect the geomembrane against the very high pressure of a large drainage gravel layer, multi-layer geotextiles, a composite geotextile or a combination of a geotextile with a thinner mineral protection layer, may be used.

Geosynthetic Reinforcement

Geosynthetic reinforcement in landfill applications involves reinforced soil structures and veneer stabilization as well as some innovative approaches to reinforce landfill covers and base liners such as horizontally placed geosynthetic reinforcements anchored into solid waste (Zornberg, 2005).
One of the growing applications of geosynthetic reinforcement in sustainable landfill construction is geosynthetic-reinforced soil structures (MSE walls and reinforced slopes) used as landfill berms for landfill vertical or composite expansion. A unique way of increasing the capacity of landfills is to build steep walls on the perimeter of the existing landfill to substantially increase the void space for waste. The purpose of the geogrid reinforced soil structures is to retain an extra height of waste within the landfill. They are lined on the waste side of the structure to contain leachate. Using geosynthetic reinforcement enables the facing of such structures to be near vertical which leads to reduction in required soil for berm construction and related transportation and placement costs and carbon emissions, and increasing the landfill capa-

city compared to traditional unreinforced berms. This technique leads to gaining immediate airspace, increasing landfill lifespan, and fully maximizing utilization of the area that has already been disturbed for waste disposal without increasing the footprint. As an example, figure 4 shows how geogrid reinforcement can provide 65% reduction in soil volume required to build a typical landfill berm compared to an unreinforced berm.

References

- Benson C.H., Daniel D.E. (1994). "Minimum Thickness of Compacted Soil Liners: II. Analysis and Case Histories". Journal of Geotechnical Engineering, ASCE, 120(1).
- Boucher, J., Friot, D., (2017). "Primary microplastics in the oceans: a global evaluation of sources", International Union for Conservation of Nature, 2017.
- Cazzuffi, D.& Recalcati, P (2021). "Landfills volume increase with reinforced soil embankments: basic theory and case studies", Detritus, Volume 15, pages 113-119, June 2021, https://doi.org/10.31025/2611-4135/2021.14092.
- Heritage, R. & Shercliff, D. (2020). "Plastic or Concrete? The use of drainage geosynthetics to replace unnecessary environmentally damaging alternatives". 7th European Geosynthetics Conference, Poland.
- Koerner, R.M. (2000). "GRI Fact Sheet – Leachate Recirculation in Municipal Solid Waste Landfills With Alternative Liners Incorporating GCLs".
- Koerner, R.M. (2012). "Designing with Geosynthetics", 6Th Edition Vol. 1, Volume 1, Xlibris Corporation, 2012, ISBN: 1462882900, 9781462882908, P.526.
- Shahkolahi, A. (2023). "Sustainable Landfill Design", 4th African Regional Conference on Geo-synthetics, Cairo.
- von Maubeuge, K. (2018). "Carbon Footprint and Sustainability of a Geosynthetic Clay (GCL) Liner in a Landfill Cap". VERSOS18: Integrando Los Vertederos En La Economía Circular. Bilbao, 7-8 November 2018.
- Zornberg, J.G. (2005). "Geosynthetic Reinforcement in Landfill Design: US Perspectives." International Perspectives on Soil Reinforcement Applications. ASCE Geotechnical Special Publication No. 141, Zornberg, Gabr, and Bowders (Editors), Austin, Texas, January.