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Geosynthetics 101

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Disclaimer

This book has been developed with the assistance of OpenAI GPT-3.5, <https://chat.openai.com/>, an advanced language model designed by OpenAI. The technology has played a significant role in shaping the content and structure of this work, contributing to the overall creative process.

Additionally, the images utilized in this book are sourced from free stock repositories or generated by the AI generator Blue Willow v4, <https://www.bluewillow.ai/>. This AI tool has been employed to produce visuals that complement the content and enhance the overall presentation.

The collaborative efforts of human creativity and technological innovation have been instrumental in the completion of this project. It is important to recognize the role of both human and artificial intelligence in the creation of this book.

Introduction

Overview of Geosynthetic Materials



Figure 1. Multiple Geogrids. Public Domain Media. (Marily475, 2008)

Geotechnical projects are renowned for their inherent complexity, primarily because they involve the manipulation of the Earth's subsurface, which is subject to a wide array of geological, environmental, and engineering variables. These projects necessitate a profound understanding of the local geology, soil behavior, groundwater conditions, and seismic factors, all of which can vary significantly from one location to another. Additionally, the intricate interplay between natural forces and human-made structures requires engineers to anticipate and mitigate numerous challenges. Consequently, geotechnical projects demand meticulous planning, thorough site investigations, and innovative engineering solutions to address the complexities associated

with soil mechanics, foundation design, slope stability, and environmental considerations.

Geosynthetics are engineered materials designed for use in geotechnical, civil, and environmental engineering. They come in various forms, including Geotextiles, Geogrids, Geomembranes, Geosynthetic Clay Liners, and many others, each with unique properties and applications. These synthetic materials have become crucial in geotechnical engineering due to their versatility and effectiveness in addressing diverse soil and construction challenges that would originally require more complex and resource consuming solutions.

The scope of use for Geosynthetics is vast and truly deserves a deep analysis of the different uses and best applications for each type. In general, we will go over some of the most common benefits of these materials. First and foremost, Geosynthetics are crucial for soil reinforcement, significantly enhancing soil stability and load-bearing capacity. This pivotal role finds applications in various projects, such as retaining walls, embankments, and road construction, ensuring the longevity and safety of these structures. Moreover, Geosynthetics play a fundamental role in erosion control, effectively preventing soil erosion and sediment transport, particularly in areas susceptible to water runoff. Their versatile capabilities extend to aiding in filtration and drainage, facilitating efficient water flow while preventing soil clogging, which proves indispensable in subsurface drainage, filtration systems, and landfills. Furthermore, Geosynthetics are essential for separation, preventing the mixing of dissimilar soils and materials, ensuring the stability and integrity of engineered structures. Their versatility extends to containment, as some

Geosynthetics serve as environmental protectors by acting as barriers to contain hazardous materials and pollutants, thereby safeguarding the environment.

Additionally, the cost-efficiency of Geosynthetics is exceptional, significantly reducing the need for extensive excavation, material transportation, and construction time, ultimately leading to substantial project cost savings. Lastly, the sustainability aspects, versatility, durability, and adaptability of Geosynthetics render them an indispensable component of modern geotechnical engineering. They contribute to innovative, resilient, and eco-friendly solutions that address the multifaceted challenges of today's infrastructure projects.

In the upcoming chapters of this book, we will delve deeper into the world of Geosynthetics. We'll begin by exploring their historical development, significant milestones, and evolution over time to provide a comprehensive understanding of their origins and journey in the field of geotechnical engineering. We will then shift our focus to the most commonly used Geosynthetics, including Geogrids, Geotextiles, Geomembranes, and Geosynthetic Clay Liners, offering in-depth insights into their composition, properties, and wide-ranging applications. Additionally, we will embark on an exploration of other Geosynthetics materials, shedding light on their unique characteristics and specialized uses.

Throughout this book, we will accompany you on a journey that includes real-world case studies and practical implementations of Geosynthetics in various geotechnical and civil engineering projects. These case studies will showcase the effectiveness and versatility of Geosynthetics in solving complex engineering challenges. Lastly, we will peer into the future, discussing emerging trends and

innovations in the realm of Geosynthetics, providing a glimpse of what lies ahead in the ever-evolving field of geotechnical engineering.

Chapter 1

History and Evolution of Geosynthetics

Early Use and Development of Geosynthetic Materials

The history of Geosynthetics is a journey that began long before the field had acquired its modern terminology. Centuries ago, inventive engineers and road builders grappled with the age-old challenge of soil stabilization, employing ingenious methods that laid the foundation for what we now know as Geosynthetics. History reveals the ingenious use of natural materials, like tree trunks, bamboo, stones, straw, and small brush, in attempts to fortify challenging terrains. These resourceful builders, more than two millennia ago, devised innovative solutions such as constructing "corduroy" roads using logs or tree limbs. These early endeavors centered around stabilizing soils with limited load-bearing capacity, representing the embryonic stage of Geosynthetics' evolution. The United States marked a pivotal moment in Geosynthetics' history during the 1920s with the introduction of textiles in road construction. This era heralded the inception of woven Geotextiles, albeit initially utilized primarily for erosion control. (Keller & Berry, 2017)

As the 1960s dawned, the field of Geosynthetics witnessed a crucial milestone with the emergence of both woven and nonwoven Geotextiles. Often referred to as "filter fabrics"

during this era, these nascent Geosynthetics assumed essential roles in an array of civil engineering projects, encompassing applications like retaining walls, enhanced drainage systems, and more efficient filtration. While the early use of Geosynthetics often encompassed experimental applications, these materials gradually evolved to assume well-defined roles in engineering tasks. Specific functions came to the fore, including drainage, filtration, separation, and reinforcement. These functions found application in diverse contexts, spanning subsurface drainage, the isolation of aggregate from soft subgrade soils to prevent contamination, soil reinforcement within mechanically stabilized earth (MSE) retaining walls, interlayers within pavements, and innovative erosion control techniques. (Keller & Berry, 2017)

Over the last 45 years, geosynthetic materials have undergone a transformative metamorphosis. Modern Geosynthetics now include not only Geotextiles but also Geonets, Geogrids, geocells, geofoam, geocomposites, plastic pipe, plastic fencing, impermeable membranes, and liners. These materials have experienced significant advancements, tailored with specific strength and durability properties attuned to their intended functions. It's intriguing to note that the discipline of Geosynthetics existed before it had acquired a formal nomenclature. Terms like "geotextile" and "Geosynthetics" were not coined until Dr. JP Giroud's seminal paper and presentation at an engineering conference in Paris in 1977. This event later became known as the First International Conference on Geosynthetics (1 ICG). Even before these terms were introduced, Geotextiles were already in use, such as in the Dutch Delta Works flood protection scheme in the early 1960s. The utilization of Geotextiles in the Delta Works engineering response was

instrumental in its exceptional long-term durability, earning it the prestigious distinction of being recognized as one of the Seven Wonders of the Modern World by the American Society of Civil Engineers (ASCE). The Geosynthetics field owes much to early pioneers like Prof. Georg Heerten, who published an article in 1984 on "Geotextiles in coastal engineering—25 years' experience."

Chapter 2

Geogrids

Geogrid Fundamentals



Figure 2. Uniaxial Geogrid. Free Stock Media. (Jonsson, 2023)

Geogrids, a type of geosynthetic material composed of polymer compounds, have found widespread use in transportation, infrastructure, and structural projects. These versatile materials are employed for soil stabilization purposes, ranging from reinforcing walls to supporting embankments and even in remote-sensing applications. Geogrids come in various different polymers with different characteristic and forms, including uniaxial, biaxial, and triaxial configurations, offering flexibility in design to match specific load-carrying requirements, these different characteristics will be comprehensively analyzed in this chapter.

Regarding the history of Geogrids, in the 1950s, Dr. Brian Mercer pioneered the concept of Geogrids, patenting the 'Netlon process' for molding molten plastic into a grid resembling a fishing net. While this innovation gained commercial traction, Mercer aimed for broader applications in civil engineering, envisioning stronger and more robust Geogrids. In 1978, after years of development, Mercer introduced the 'Tensar process,' yielding Geogrids with significantly enhanced strength and durability. Fast forward nearly four decades, and Tensar Geogrids have become integral to numerous global projects, with Mercer dedicating two decades to perfecting Tensar technology. This innovative process realigned polymer molecules, strengthening both the grid's horizontal and vertical ribs and their junctions, resulting in a plastic grid rivaling the strength of steel. A trial in 1980 showcased the effectiveness of Tensar Geogrids, demonstrating their ability to support a 2.5-meter-high retaining wall under heavy loads with no noticeable settlement over three years. (Tensar - ISSMGE Time Capsule Project 2022, 2022)

Properties Of Geogrids

Manufacturing

There are various ways that Geogrids are manufactured, some of the most common ones are the following:

Extrusion: One of the most common methods for producing Geogrids. It involves melting the polymer material, and then extruding it through a die to form a continuous sheet. The sheet is then stretched in one or both directions to create a grid-like structure with apertures or openings. The stretching process aligns the polymer molecules, enhancing the geogrid's strength.

Knitting and Weaving: Some Geogrids are manufactured by knitting or weaving polymer yarns into a grid pattern. The tension in the yarns and the interlocking of the strands create the grid structure.

Welding: Welding is another method used to create Geogrids, especially for more complex or specialized designs. In this process, individual ribs or strands are extruded separately and then welded together at the junctions to form the grid. This allows for precise control over the grid's geometry and properties.

Polymers

Geogrids are typically made from various synthetic polymers, each offering specific advantages and properties suited to different applications. Some of the commonly used polymers for manufacturing Geogrids include.

- High-Density Polyethylene
- Low-Density Polyethylene
- Polyethylene Terephthalate
- Polypropylene
- Polyvinyl Chloride

Design

Uniaxial Geogrids: Uniaxial Geogrids are designed to provide strength and reinforcement primarily in one direction, typically along the roll's length. They have prominent ribs and apertures that are oriented along this primary direction. Uniaxial Geogrids are typically utilized when primary loads or stresses are anticipated to occur in a single direction. (Happho, 2023)

Biaxial Geogrids: Biaxial Geogrids are engineered to provide strength and reinforcement in two perpendicular directions, typically both along the length and width of the roll. Biaxial Geogrids are versatile in application due to its capacity of evenly distributing load in applications where stresses come from various directions and its robust confinement of granular material. (Happho, 2023)

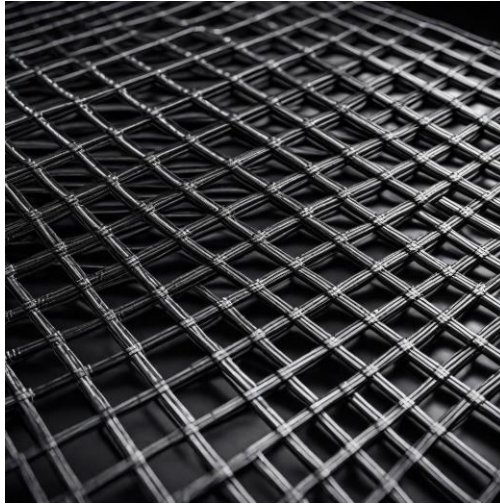


Figure 3. Biaxial Geogrid. BlueWillow V4 AI Generated.

Triaxial Geogrids: Triaxial Geogrids are designed to offer strength and reinforcement in three directions, typically along the length, width, and diagonally. The choice for triaxial Geogrids is usual for projects where high-stress is expected, and the load-bearing capacity needs to be even in all directions. In comparison to biaxial Geogrids, triaxial can in some cases reduce the lateral confinement of granular material, which for some applications would cause a reduction in the reinforcement of elements like pavement. (Happho, 2023)

Aperture

The mechanical properties and characteristics of Geogrids are significantly influenced by the shape of their apertures. Smaller aperture sizes result in inadequate interlocking between the geogrid and soil, leading to widely varying outcomes. Conversely, larger aperture sizes reduce the frictional interaction between the geogrid and soil. Optimal interaction between the geogrid and soil occurs when the aperture size closely matches the size of soil grains.

In the case of rectangular aperture Geogrids (biaxial), it's noteworthy that tensile strength and stiffness vary depending on the direction. Triangular aperture Geogrids (triaxial), on the other hand, exhibit a more uniform distribution of stress, contrasting with their rectangular counterparts. Consequently, the triangular aperture geogrid demonstrates greater efficiency in carrying off-axis stresses that deviate from the primary directions. (Al-Barqawi, et al., 2021)

Nodes

The nodes of Geogrids are pivotal for their mechanical behavior. Tensile experiments have shown that geogrid failure is often due to joint and edge ruptures, emphasizing the importance of these connections. Geogrids can be connected through overlapping or frictional mechanisms, which depend on the geogrid's shear strength, or via mechanical connections for added structural rigidity, commonly used in soil-retaining walls. Understanding and optimizing these nodes and connections is vital for geogrid performance in geotechnical applications. (Al-Barqawi, et al., 2021)

Installation

Achieving a successful geogrid installation involves several key considerations. It's advisable to start by ensuring that

you have access to the right tools and equipment for the job. Many Geogrid suppliers offer tools specifically designed to simplify the installation process. Additionally, it's important to be aware of local regulations and permitting requirements, as they may dictate the maximum depth, size, and type of Geogrids allowable in your area. Geogrid installation techniques tend to be simple, requiring usual practices like debris elimination, elevation checks, smooth grading, compaction, and in some cases proof rolling. Once the surface is properly prepared, the geogrid is manually unrolled over it. Geogrids typically come in large rolls, and they are laid out like a mat, covering the area that requires reinforcement. In some cases, after unrolling, wrinkles or waves may appear in the geogrid or the underlying aggregate. To rectify this, anchoring or pulling techniques may be employed. Anchoring involves securing the geogrid to the ground at specific points, while pulling applies tension to the geogrid to remove wrinkles and ensure it lies flat, optimizing its performance and effectiveness in reinforcing the construction site. While a 6-inch initial lift of aggregate fill is generally sufficient for geogrid applications, it's crucial to adapt this thickness when dealing with very soft soil conditions. In such cases, a thicker fill layer becomes essential to maintain the stability and structural integrity of the construction project, preventing adverse consequences such as rutting or subgrade failure.

Applications of Geogrids

Retaining Walls

Retaining walls are engineered structures designed to resist the lateral pressure exerted by soil or other materials when there is a change in ground elevation. They are typically constructed to create terraced levels or flat surfaces on

uneven or sloping ground, preventing soil erosion, and providing stability to landscapes and infrastructure. Geogrids application in retaining walls primarily revolves around the realm of soil backfills. Geogrids play a crucial role in increasing the stability of retaining wall structures by binding the soil together. By reinforcing the soil, Geogrids substantially improve its structural integrity. This reinforcement serves a dual purpose: containing the backfill material securely and evenly distributing the applied loads.

Geogrids prove particularly important when dealing with challenges like soft or sloping ground conditions, as they mitigate the associated issues. One advantage of employing Geogrids in retaining walls is the potential for extending their length. This extension allows to increase the overall mass of the retaining wall structure. Consequently, it becomes feasible to construct taller retaining walls with greater stability.

The use of Geogrids to reinforce retaining walls has witnessed a significant surge in demand across various project types. This heightened interest can be attributed to several key attributes, including its flexibility and ability to adapt to deformation, resistance to earthquakes, cost-effectiveness, and its capacity to promote plant growth. These qualities collectively bolster the case for integrating Geogrids in retaining wall construction. (Tensar, 2021) (The Constructor, 2021)

Foundation Soil Stabilization

Geogrids find application in soil stabilization for shallow foundations by significantly augmenting the load-bearing capacity of the underlying soil. Several intrinsic properties of Geogrids contribute to this enhancement. Primarily,

Geogrids facilitate the uniform distribution of applied loads across a broader expanse of soil, thereby mitigating localized soil deformation and the risk of shear failure. The substantial tensile strength exhibited by Geogrids in both longitudinal and transverse directions serves to enhance the tensile strength of the surrounding soil.

Furthermore, Geogrids function as effective soil particle confiners within their apertures, effectively curbing lateral soil movement and potential load shifts resulting from compression. This confinement effect ensures that the soil maintains its compactness and structural integrity under the influence of external loads.

In addition to their confinement and load-distribution roles, Geogrids assist in diminishing differential settlement, a crucial factor in sustaining foundation stability over time. Through collaborative interaction with the soil, Geogrids create a reinforced composite structure where the collective load-bearing capacity is significantly elevated. This methodology proves particularly advantageous in scenarios involving less stable or weaker soils that would otherwise pose a challenge to foundation stability. (Tensar, 2021) (The Constructor, 2021)

Pavement Construction

The utilization of Geogrids in pavement construction represents an approach to addressing several critical aspects of pavement performance. Firstly, Geogrids play a pivotal role in subgrade improvement. The subgrade, as the fundamental load-bearing layer, is fortified and stabilized through the incorporation of Geogrids. This intervention is particularly beneficial when dealing with soft or less

supportive subgrade conditions, as it effectively mitigates issues related to subgrade weakness.

Moreover, Geogrids contribute to the reinforcement of the pavement base. Traditionally, increasing the thickness of the base layer is a viable method to enhance its stiffness. However, excessive thickness can be both economically impractical and operationally inefficient. Geogrids offer an alternative by reinforcing the existing base layer, which results in a notable stiffening effect. This not only reduces the need for excessive base thickness but also accelerates construction timelines. Additionally, the reinforcement of the base layer extends the overall lifespan of the pavement, thereby improving its long-term durability.

Flexible pavement structures frequently encounter premature failures due to progressive lateral and vertical displacement, often coupled with a weakening of the aggregate base course. Geogrids address these challenges by elevating the overall stiffness of paved structures that bear vehicular traffic. They achieve this by confining and interlocking with the aggregate materials, creating a mechanically stabilized layer (MSL). This layer minimizes the maintenance and rehabilitation intervals that are commonly associated with flexible pavements. (Tensar, 2021) (The Constructor, 2021)

Other Applications

Geogrids have a wide range of applications, including some less commonly known use. One such application is in stabilizing rail tracks, where Geogrids are placed between ballast layers, typically composed of gravel, to efficiently distribute loads and reduce track settlement. Geogrids also play a vital role in various environmental protection

processes, including erosion reduction for shoreline protection, mitigation of scour and the effects of waves and tides on structures, support for marine structures, and even facilitating vegetation growth. Their lightweight nature and ease of handling make Geogrids a valuable choice in mining projects, where they provide support for roofs and help minimize the risk of rockfalls. (Tensar, 2021)

Advantages and Limitations of Geogrids.

Advantages

By having different patterns, Geogrids offer multiple options for different uses based on the different stress transfers. The variations in Geogrids aperture allow to use them for interlocking a wide range of granular or fine material sizes. Geogrids provide a significant reduction in cost for elements like retaining walls in replace of materials like concrete. Geogrids are often considered environmentally friendly due to the capacity of plants and vegetation to thrive in between the apertures.

Installation techniques are simple, and repairs of damaged geogrid only require patching. Once Geogrids are installed, reinforced structures typically require less maintenance over their lifespan. Geogrids flexibility allow for adaption to uneven terrains.

Limitations

Some Geogrids tend to degrade due to long-term UV exposure, if Geogrids are not properly covered, structural properties can suffer. If not recognized in the installation process, wrinkles and waves can affect the performance of the geogrid material.

Flaws in manufacturing processes can cause Geogrids to not provide uniform tensile strength throughout all its directions. In some cases, these different tensile strengths are recognized but manufacturers and specified, which is key in determining design approaches.

As all other Geosynthetics, due to the nature of polymer materials, time can cause deformation due to external factors such as elevated temperatures from construction process and stress. This is what is known as creep failure.

It is important, in order to avoid these limitations to affect project success, to perform Geosynthetics work in accordance with manufacturers recommendations and characteristics of the specific geosynthetic being used. In no case it can be assumed that all Geogrids behave the same only because of shape similarity, and aperture similarities. Other not so explicit properties, like material composition and nodes heavily affect the performance of Geogrids.

Chapter 3

Geotextiles



Figure 4. Geotextile. Free Stock Media. (Tunas, 2023)

Geotextiles Fundamentals

Geotextiles are a type of geosynthetic material known for their composition of various polymer compounds and intricate design. These versatile textiles play a central role in various sectors, including transportation, civil engineering, and environmental management. Within soil and foundation engineering, Geotextiles offer dynamic solutions, finding widespread application in erosion control to protect against soil loss from wind and water forces. They also facilitate efficient drainage systems, enhance soil stability in retaining walls and embankments, and serve as effective filters against contaminants. Innovative uses extend to green infrastructure projects, promoting sustainable urban development. Throughout this chapter, we will explore the multifaceted

characteristics and common applications of Geotextiles while also discussing the principal differences in characteristics and uses compared to other Geosynthetics within the realm of construction and infrastructure projects.

Geotextiles are widely regarded as one of the earliest geosynthetic materials used. Before the term “geotextile” was coined, textiles (not polymers) were employed in highway construction projects as far back as the 1920s, primarily for drainage and erosion control purposes. In the 1950s, woven natural fibers gained recognition for their effectiveness in erosion control, drainage, and even soil reinforcement. During this era, these Geosynthetics were often referred to as “filter fabrics” or “fabric walls.” Initially, small textile companies and chemical companies saw an opportunity in this emerging market. (Gateway Structure SDN BDH, 2023)

In the 1960s, polymer materials made their debut in Geotextiles when professionals in the Netherlands utilized them for the Delta Works flood protection scheme, a response to the North Sea floods of the 1950s. This project catapulted Geotextiles into the world of civil engineering, leading to their widespread adoption in coastal projects, particularly in the Netherlands, the United States, and Germany. (Kelsey, 2014)

During the 1970s, Dr. Jean Pierre Giroud began incorporating Geotextiles and Geomembranes into engineering projects, employing them for filtration and embankment reinforcement. In 1977, he officially named Geotextiles and Geomembranes in his publication, “Classification des textiles et mesure de leurs propriétés en vue de leur 26tilization en geotechnique,” which translates to "Classification of textiles and measurement of their

properties for their use in geotechnics." (Giroud & Perfetti, 1977)

In 1984, Professor Georg Heerten published the inaugural issue of the journal "Geotextiles & Geomembranes," reflecting on 25 years of experience using these materials in coastal engineering projects. Subsequently, significant progress has been made in geotextile manufacturing, with advancements such as improved polymeric materials, enhanced cost-effectiveness of production, and overall improvements in the engineered characteristics of Geotextiles. (Kelsey, 2014)

Properties of Geotextiles



Figure 5. Multiple Type of Geotextiles. Public Domain Media. (Marilyn475, Geotextiles1.jpg, 2008)

Manufacturing and Design

Woven: Woven Geotextiles are created through a weaving process that intertwines individual threads on a loom, resulting in a uniform fabric length. These Geotextiles are well-suited for reinforcement applications because they are typically less permeable than their counterparts. Their

resistance to corrosion makes them particularly durable for long-term use. (BlueStone Supply, 2023)

Nonwoven: Nonwoven Geotextiles, on the other hand, are manufactured by binding both long and short fibers together using methods like needle punching or heat treatments. While they may not be as robust for reinforcement applications, they excel in filtration and separation tasks due to their permeable nature. (BlueStone Supply, 2023)

Knitted: Knitted Geotextiles are manufactured by interlocking loops of yarn together, the number of knitted Geotextiles that are produced is reduced. (Agrawal, 2011)

Polymers

Geotextiles are typically made from various synthetic polymers, each offering specific advantages and properties suited to different applications. Some of the commonly used polymers for manufacturing Geogrids include.

- High-Density Polyethylene
- Low-Density Polyethylene
- Polyethylene Terephthalate
- Polypropylene
- Polyamide

Physical and Mechanical Properties

Geotextiles possess a range of physical and mechanical properties critical to their performance in diverse applications. Specific Gravity, varying based on the polymer material used, plays a pivotal role, especially in water-related projects, where maintaining a value over 1 is essential for buoyancy and effectiveness. The weight of circular specimens impacts specific gravity, underscoring

the need for precision. Geotextile thickness is another key factor, influencing permittivity and transmissivity, determining how fluids flow through the fabric. Additionally, the ability to resist bending is indicative of a geotextile's suitability for specific surfaces.

On the mechanical front, Geotextiles must exhibit resilience to compression from liquids to maintain their structural integrity. Resistance to tearing, high forces, and fatigue due to continuous loads are vital aspects, ensuring longevity and performance. Moreover, Geotextiles must withstand unexpected impacts common in construction, making their mechanical properties a critical consideration in engineering and civil projects. (Zaman, 2018)

Apertures

The specific opening size or aperture of a geotextile is typically defined in terms of its "pore size" or "opening size," and it is an important consideration when selecting the appropriate geotextile for a particular project. For practical purposes, these apertures can be classified in:

Small Aperture (0.08mm to 0.30mm): Used to trap and retain fine particles while allowing fluids to pass, effective for drainage systems, soil erosion and water quality improvements.

Medium Aperture (0.30mm to 0.60mm): Versatile, can provide filtration, separation and drainage and provide benefits in reinforcement.

Coarse Aperture (> 0.60mm): Used in drainage when rapid water flow is required to facilitate drainage and serve as reinforcement element due to its capacity to distribute loads.

Installation

Achieving a successful geotextile installation involves several key considerations. It's advisable to start by ensuring that you have access to the right tools and equipment for the job. Many geotextile suppliers offer tools specifically designed to simplify the installation process. Additionally, it's important to be aware of local regulations and permitting requirements, as they may dictate the maximum depth, size, and type of geotextile liners allowable in your area. Properly preparing the installation site is a fundamental step. This includes clearing the surface of vegetation, removing any obstructions, and addressing weak soil areas with appropriate fill materials. Ensuring that the subgrade is level and free from unevenness is essential. Selecting the correct size of geotextile liner is crucial to match the project's specifications. When overlapping rolls of geotextile, it's a good practice to follow project-specific guidelines. In cases where specific instructions are lacking, a common approach is to overlap geotextile rolls by a minimum of 12 to 18 inches. The American Association of State Highway and Transportation Officials (AASHTO) provides valuable recommendations for determining overlap requirements. Lastly, securing the geotextile fabric along its edges is essential. This can be achieved using suitable materials such as soil, pins, and staples, making sure that there is proper overlap at critical points. By adhering to these general principles and best practices, you can enhance the likelihood of a successful and durable geotextile installation in various construction and engineering applications. (Western Environmental Liner, 2016)

Permeability

In addition to aperture, which we discussed earlier, another crucial factor influencing hydraulic properties is permeability. Geotextiles vary in permeability depending on their construction and the polymer used. Woven and knitted Geotextiles tend to offer higher permeability, making them suitable for applications where rapid water flow is needed, like drainage systems. Nonwoven Geotextiles, with lower permeability, are preferred for applications focused on filtration and separation, where controlled water flow is essential. The choice depends on the specific water flow requirements of the project, taking both aperture and permeability into account. (Zaman, 2018)

Applications of Geotextiles



Figure 6. Woven Geotextile. Free Stock Media. (photowind, 2023)

Separation

It is a crucial application of Geotextiles to separate diverse materials by strategically placing a flexible porous textile

between them in order to improve the performance of both. In the realm of transportation, Geotextiles play a pivotal role in preventing the mixing of two adjacent soil types. For instance, by separating fine subgrade soil from the aggregates within a base course, Geotextiles effectively safeguard the drainage and strength properties of the aggregate material. Various road classes and civil foundations can benefit from these applications, since avoiding construction on contaminated layers will help prevent premature failure. Geotextile separators mitigate the effects of dynamic loads, preventing the unwanted ejection of soil and water, all while allowing water to pass through and retaining soil particles. Roads, railroads, sidewalks, curbs, and parking lots are often constructed using Geotextiles between subgrade and stone bases for separation purposes. It is important to consider factors such as permeability, strength, grain size distribution, and compatibility with the adjacent soil when selecting Geotextiles for separation. (Dhanapal, 2006)

Filtration

Geotextiles filter fluids by allowing efficient liquid flow while minimizing soil loss over their service lives. The main factors influencing filtration performance are permeability and porosity. It is vital that Geotextiles permit liquid flow while preventing the buildup of excess water pressure in the soil. This characteristic helps maintain the stability and integrity of structures, such as roadways and embankments. Additionally, the aperture design of Geotextiles is key to strategically retain soil particles while permitting flow. In practical applications, Geotextiles excel when they replace conventional graded aggregate filters in both horizontal and vertical drain systems. (Agrawal, 2011)

Drainage

In constructions ranging from groundwater intercept systems and pavements to building foundations, dams, and walls, Geotextiles have replaced typical graded soil filters. Geotextiles offer a constant and ongoing filtering function that significantly decreases the need for excavation, the environmental impact of construction processes, and enhance construction quality, while reducing material costs. Particularly where the retention of tiny soil particles is essential for the effective operation of drainage systems, nonwoven Geotextiles excel.

Although Geotextiles are essential for both filtration and drainage, it is important to note that there are key differences between the two. Geotextiles in drainage essentially encourage the effective flow of water through their planes; In filtration, the main emphasis is to balance the flow of liquid while reducing soil loss that affects structural stability. (Agrawal, 2011)

Reinforcement

Applications for geotextile reinforcement include levees, retaining walls, and embankments built over soft soils, demonstrating its adaptability. They work particularly well for building walls with different facing materials, like segmental blocks, precast panels, and wood. Cost-effectiveness is a common trait of geotextile-based solutions, with geotextile retaining walls frequently costing less than half as much as conventional walls.

The capacity of woven Geotextiles to streamline installation and construction procedures in reinforcing applications is one of their noteworthy benefits. They also give the option

to use on-site backfill materials, further expediting construction processes.

Three main mechanisms are responsible for geotextile reinforcement:

Friction between the geotextile and the surrounding soil or aggregate providing lateral restriction and preventing unintentional shifts or movements.

Forcing the probable failure plane of the bearing surface to generate surfaces with increased shear strength, improving stability.

Supporting wheel loads in a manner similar to a membrane and dispersing soil stress more evenly.

Using Geotextiles for reinforcement, is, in some cases, similar to reinforcing concrete with steel, taking advantage of the tensile strength of geosynthetic materials. (Agrawal, 2011) (Dhanapal, 2006)

Other Applications

Beyond their core tasks in separation, filtration, drainage, and reinforcement within civil engineering and building projects, Geotextiles fulfill additional functions. Geotextiles are crucial for stabilizing railway tracks because they stop subgrade debris from seeping into the ballast above, maintaining an equal track bed and promoting secure and efficient train operations. Geotextiles have applications in waste containment systems for a variety of tasks, including as filtration in fluid and gas collection systems, defense of geomembrane liners, reinforcement of containment structures, and production of long-lasting waste daily coverings. Geotextiles are also used in a number of crucial locations, including shorelines, drainage channels, and scour

protection systems for bridges and piers, to reduce erosion. Finally, Geotextiles soak asphalt to transform into a waterproofing membrane in sealing applications, reducing vertical water flow into the pavement structure, and improving the lifespan and efficiency of roads and other covered areas. (Dhanapal, 2006)

Advantages and Limitations of Geotextiles.

Advantages

Geotextile provide ease of handling thanks to their weight, improving logistics and installation efforts. Geotextiles have high shear strength which make them durable and resistant to damage. Geotextiles offer customization options, allowing specifications like permeability, tensile strength, and UV resistance to match project requirements. Biodegradable Geotextiles are increasingly available, promoting natural decomposition without synthetic residue. Geotextiles are considered to be the most versatile type of geosynthetic due to their vast number of uses. Sustainable materials, including natural alternatives to polymers, can be used as Geosynthetics, offering eco-friendly choices with similar benefits. (Cardigan Sand & Gravel CO Ltd, 2023) (Patil, 2023)

Limitations

Geotextiles can become blocked by various elements like sediments, organic matter, roots, algae, or chemicals, hampering filtration and drainage, and sometimes requiring replacement. In shallow upper layers or areas with activity, Geotextiles may rip, potentially mixing upper and lower layers and obstructing fluid flow. Geotextiles can hinder seed germination by blocking sunlight and moisture. (Cardigan Sand & Gravel CO Ltd, 2023) (Patil, 2023)

Chapter 4

Geomembranes

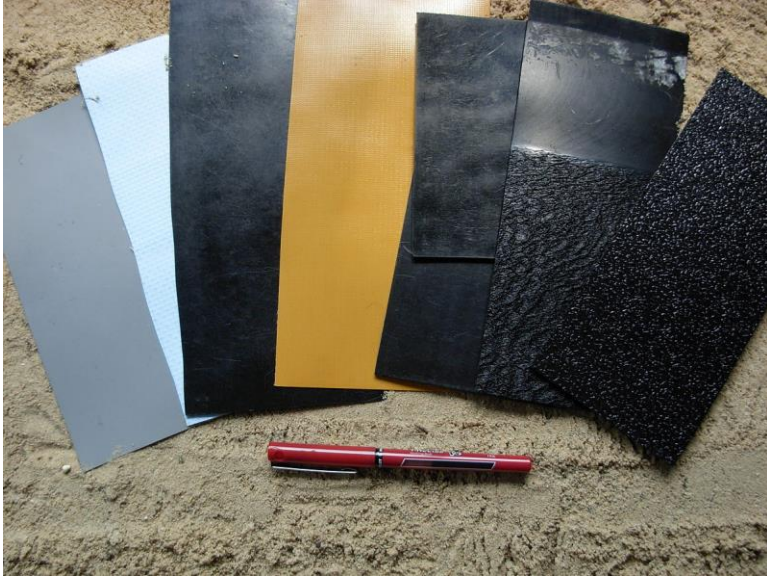


Figure 7. Different Geomembranes. Public Domain Media. (Marilyn475, Geomembrane-GSI.JPG, 2008)

Geomembranes Fundamentals

Geomembranes, a versatile class of Geosynthetics, are at the core of modern geotechnical engineering and environmental protection. Continuous polymeric sheets, often made of thermoplastic or thermoset polymers, make up these impermeable barriers. Despite having a common misconception of being impervious, Geomembranes really have a relatively low hydraulic conductivity, making them what is known as "essentially impermeable." They are vital in environmental engineering projects that aim to address problems like seepage control, solid waste landfill

management, and waterproofing that are related to the prevention of liquid and gas migration since their principal function is containment. Due to their critical role in projects that address environmental challenges, Geomembranes produced a sizeable \$1.8 billion in sales revenue in 2015, making them the top geosynthetic product in terms of financial value.

In the early 1960s, Geomembranes first became popular as a method of environmental containment, particularly for preventing leaching at sites of hazardous waste. Geomembranes have developed throughout time to become crucial elements in many other industries and processes, considerably exceeding their original function. Beginning in the 1970s, geomembrane liners became popular in the mining industry, revolutionizing how the sector approaches containment and environmental protection.

In addition to mining, Geomembranes have found use in a variety of industries, such as agriculture, waste management, marine construction, and water resource management. Geomembranes continue to offer outstanding tear strength, elongation, and puncture resistance thanks to continued technical developments, offering dependable solutions catered to specific environmental and project specific needs. (Müller & Saathoff, 2015) (Breitenbach & Smith, 2016) (Eric, 2023)

Properties of Geomembranes

Materials

PVC Geomembranes: Ethylene dichloride is converted into a vinyl chloride monomer, which is then polymerized to produce PVC resin to make PVC Geomembranes, which are composed of vinyl, plasticizers, and stabilizers. These

Geomembranes are exceptional in resisting damage, guarding against tears, punctures, and abrasions, making them ideal for protecting water sources and ensuring the safety of drinking water. Because of their adaptability, they are a preferred choice for applications such as landfill linings, canal linings, tank linings, soil remediation, and wastewater lagoon liners. (Eric, 2023) (Ait, 2021)

EDPM Geomembranes: Ethylene Propylene Diene Monomer rubber is used to create EPDM Geomembranes, which have remarkable elasticity and temperature tolerance. Because of its UV protection, they can withstand continuous sun exposure without deteriorating. EPDM Geomembranes are highly valued in large-scale projects due to their durability, where their strength and resistance to water and chemicals stand out. (Eric, 2023) (Ait, 2021)

RPP Geomembranes: Reinforced The UV-stabilized polypropylene copolymer used to make polypropylene Geomembranes has the key properties of flexibility, stability, and chemical resistance. These Geomembranes are most helpful in environments where folds might appear as a result of erratic weather. Their enduring strength and toughness are ensured by the presence of a supporting nylon scrim. RPP Geomembranes are frequently used as evaporation pond liners, in horticulture, aquatic habitats, municipal settings, and in the management of mining tailings. (Ait, 2021)

TRP Geomembranes: Reinforced Polyethylene (TRP) Geomembranes are extremely resilient, use polyethylene fabric rather than polyester, and are useful for activities involving soil remediation. Their prominent characteristics include stability under UV exposure, adaptability for a wide temperature range, and resistance to chemicals. This kind of geomembrane is used in a variety of settings, including

landfills, industrial tarps, waterways, and municipal and agricultural purposes. (Ait, 2021)

HDPE Geomembranes: High-Density Polyethylene (HDPE) Geomembranes resist tearing and puncturing, ensuring secure containment. They are also resistant to industrial chemicals, making them perfect for applications where chemical seepage could occur. They also protect against UV deterioration and microbial development, making them suited for a variety of climates and sunshine exposure. (Eric, 2023) (Ait, 2021)

FPP Geomembranes: FPP Geomembranes are generally chosen liners for waste containment in landfills and ponds. Due to their fluoropolymer resin composition and ability to tolerate harsh environmental conditions, they excel in chemical and UV resistance. FPP Geomembranes are a popular option for waste containment due to their adaptability, which enables customization of thickness and width to fit particular project needs. (Eric, 2023)

Seaming and Installation

Effective seaming and installation of Geomembranes is essential for containment, structural stability, cost efficiency, and regulatory compliance. It prevents hazardous leakage, safeguards the environment, and minimizes repair costs, ensuring compliance with regulations.

Extrusion Seam: Fusion welding used to create the jointure on polyethylene Geomembranes. In order to attach the surfaces, molten polymer from other sources is used between them. (Eric, 2023) (Das & Sobhan, 2016)

Thermal Fusion Seam: This technique uses hot air to melt the geomembrane sheets' opposing surfaces, then pressure to bind them together. (Das & Sobhan, 2016)

Chemical Fusion Seam: In this method, the edges of the geomembrane sheets are treated with a liquid solvent before pressure is applied to guarantee complete contact between the two edges. (Das & Sobhan, 2016)

Adhesive Seam: This method consists in coating the mating surfaces of the geomembrane sheets with bonding chemicals. The two edges are then brought into alignment and compressed to make complete contact. (Das & Sobhan, 2016)

Applications of Geomembranes

Waste and Landfill Management

Geomembrane liners provide adaptable ways to improve the ecological sustainability and landfill performance. In both primary and secondary solid-waste landfills, geomembrane liners function as a strong barrier against waste seepage, preventing groundwater pollution. By using alternate daily coverings in place of soil, they transform the daily processes involved in covering landfills. This replacement not only reduces odors but also discourages scavenging, fires, littering, and vectors. (IWT Cargo-Guard, 2019)

In addition, these liners are excellent at redirecting rainfall from landfill pits and are essential to landfill tops because they stop the flow of waste liquids produced after filling. Moreover, the degradation of landfill garbage releases gases that geomembrane caps effectively absorb. Containment system design for landfills is a complex process that involves several factors, including liner longevity, temperature fluctuations, chemical reactions, leachate and gas

management, and regulatory compliance. During the closure and post-close periods, the complexity increases, and creative solutions are required.

Mining

In the mining sector, Geomembranes play essential roles in protecting the environment and optimizing mining operations.

Geomembranes serve primarily as a barrier to shield soil and groundwater from the chemical solutions used in heap leaching, which is a method of recovering low-grade minerals. In order to ensure compliance with environmental requirements, they are also essential in the construction of ponds, channels, tailings storage facilities, and heap leach pads. (Shah Shivji Valji & CO, 2022)

Additionally, toward the conclusion of a mine's operating life, Geomembranes—especially High-Density Polyethylene (HDPE) liners—help seal the mine and keep trash from endangering the environment. (Breitenbach & Smith, 2016)

Water Resources.



3 Geomembrane in a pond application. Free Stock Media. (Fahroni, 2023)

Geomembranes are used as protective barriers in drinking water and wastewater services, particularly sewage treatment. Their impermeable nature keeps impurities out and guarantees that clean water is delivered safely to communities. Furthermore, Geomembranes are used to seal vital water infrastructure such as canals, dams, and reservoirs. They protect against groundwater contamination and reduce water loss owing to infiltration into the surrounding soil by lining these structures. (Ait, 2021)

Geomembranes improve the efficiency of water storage and conveyance in addition to containment. Lining dams and canals lowers seepage, preserving vital water resources, which is critical in water-stressed areas. Geomembranes also serve as secondary containment systems for subterranean storage tanks, solar ponds, and brine solutions. They act as effective barriers, avoiding leaks and spills and reducing the risk of environmental pollution. (Ait, 2021) (Müller & Saathoff, 2015)

Agriculture

Geomembranes play an important role in agricultural activities, particularly in two principal applications: storage ponds and agricultural treatment lagoons. Geomembranes are essential in the construction of storage ponds, where they function as impermeable liners. These temporarily collect agricultural waste like manure, wash water, and runoff, allowing it to decay before being applied to crops. The impermeability of the geomembrane prevents waste items from seeping into the earth, conserving groundwater, and soil quality. It's worth noting that the nutrient-rich slurry produced in storage ponds is beneficial to crop growth. Geomembranes also play an important part in agricultural treatment lagoons. These lagoons are large in size and use

Geomembranes as waste containment lining materials. They not only function as storage facilities, but they also provide enhanced treatment benefits. Geomembranes guarantee that waste is adequately kept within the lagoon, preventing seepage into the ground. Furthermore, they contribute to the stabilization of the lagoon's contents, greatly lowering odors when compared to storage ponds. (Advanced Textiles Association, 2022)

Other Applications

Geomembranes have a number of other important applications aside from their principal uses. They are critical for coastal protection, acting as a barrier against storm surges and natural disasters. Furthermore, in some cases Geomembranes provide necessary waterproofing for roads and highways, assisting in the prevention of pollution caused by the use of salt for de-icing during the winter months. They act as excellent barriers against moisture and chemical leaks, making them important for containment in the oil and gas industry, especially when High-Density Polyethylene (HDPE) Geomembranes are used, which are known for their superior chemical resistance. Geomembranes are also useful for seepage control, assisting in the management of chemical spills within storage tanks, and have applications in marine construction for dock protection, buoyancy, and protection against deterioration caused by factors like as animals, plants, and salt water currents. (Ait, 2021) (Eric, 2023) (IWT Cargo-Guard, 2019) (Shah Shivji Valji & CO, 2022) (Müller & Saathoff, 2015)

Advantages and Limitations of Geomembranes.

Advantages

Geomembranes are relatively simple to install, reducing labor costs and project timelines. When installed correctly, Geomembranes provide an impermeable barrier, preventing water leakage or contamination. Geomembranes maintain their integrity even in freezing conditions, ensuring reliable performance in diverse climates. In case of damage, Geomembranes are repairable, minimizing downtime and replacement costs. Their longevity allows for error correction and mitigates issues during long-term use. Certain geomembrane materials exhibit strong resistance to various chemicals, making them suitable for chemically aggressive environments. Geomembranes reduce costs in environmental applications such as landfills and water treatment by preventing contamination and facilitating waste containment. Due to widespread usage, there is a pool of experienced installers, ensuring proper installation and performance.

Limitations

Geomembranes can be vulnerable to punctures if not properly handled, increasing the risk of damage and leakage. Ensuring strong bonding and shear strength at interfaces with other materials or structures is crucial for geomembrane integrity. Their weight can pose logistical challenges during transportation, requiring appropriate handling and equipment. Incorrect installation or design can lead to contamination, necessitating meticulous planning and execution. Different geomembrane materials exhibit varying characteristics, which may require careful selection based on project-specific requirements and considerations.

It's important to note that the advantages and limitations of Geomembranes vary significantly based on the material used for their manufacture. Different sectors have specific requirements for the type of geomembrane material used in their applications. Analyzing the advantages and limitations of each material type goes beyond the scope of this book, but it's crucial to consider these factors for informed decision-making in geomembrane selection for specific projects.

Chapter 5

Geosynthetic Clay Liners



*Figure 9. Different Geosynthetic Clay Liners. Public Domain Media.
(Marilyn475, Geotextiles1.jpg, 2008)*

Geosynthetic Clay Liners Fundamentals

The Geosynthetic Clay Liner (GCL) emerges as a leading technique in the research of Geosynthetics, gradually gaining recognition as an important barrier system, notably in municipal solid waste landfill applications. A GCL consists of a thin coating of processed clay, commonly of the highly absorbent bentonite variety, bonded to a geomembrane or placed between two layers of geotextile. (Bouazza, 2002) Bentonite, known for its outstanding absorptive and plastic properties, plays a crucial part in this innovative combination. Its colloidal characteristics and attraction for positively charged water particles allow for quick hydration when exposed to liquids such as water or

leachate, as well as volumetric expansion when in contact with water, assuming a gelatinous and viscous form. This uncommon characteristic permits the clay to swell during hydration, giving it the ability to self-heal and plug perforations in the GCL. Experimental studies on bentonite have demonstrated its ability to self-seal holes up to 75 millimeters (von Maubeuge, 2002) (United States Environmental Protection Agency, 2001)

The history of Geosynthetic Clay Liners may be traced back to several patents submitted in the United States by Arthur G. Clem in 1962 and 1982. (United States of America Patent No. US3186896A, 1962) (United States of America Patent No. US4501788A, 1982) The initial patent was based on the use of bentonite in conjunction with paperboard to make an impermeable panel. The second invention went a step further into what is now known as a GCL, with Bentonite being used along a geotextile and adhesion procedures. Following the issuance of these patents, the late 1980s saw the widespread usage of GCL as backups to compacted clay liners, progressively gaining importance as an important component in municipal solid waste landfill control.

GCL have steadily established a reputation as a viable alternative to compacted clay liners, providing a seepage-resistant solution that deviates from the conventional method. A compacted clay liner is composed of cohesive soil that has undergone compaction to increase its bulk dry density and uniformity, with the primary purpose of reducing porosity and limiting soil permeability. (Province of Manitoba, 2007) The compacted clay liner is used in applications such as earthen manure storage to prevent liquid manure seepage. However, despite their simple construction, compact clay liners are vulnerable over time. Compaction

issues emerge in places with structurally unstable underlying layers, and without adequate protection, these liners are vulnerable to deterioration from factors such as desiccation and freeze/thaw cycles, resulting in crack formation. Animal activity and plant root penetration are also compromising factors. Importantly, once damaged, compacted clay liners have a restricted ability to be repaired. Recognizing these limitations, Geosynthetic Clay Liners have received widespread acceptance and use as a viable solution that tackles these drawbacks while also improving durability and impermeability. (Kuo, 2023)

Properties of Geosynthetic Clay Liners

Materials

The classification of GCLs is dependent on the type of Geosynthetics used, resulting in two separate classifications: Geotextile-Encased GCL, which consists of two Geotextiles wrapping a thin bentonite layer, securely tied through needle punching, stitching, or chemical adhesives; and Geomembrane-Supported GCL, which incorporates a geomembrane layer with an adhered bentonite layer bonded using environmentally friendly adhesives. In the case of GT-GCL, bentonite serves a dual purpose: it reduces the hydraulic conductivity of the liner while also enabling the repair of localized damage. In GM-GCL, where the geomembrane has low hydraulic conductivity, the major function of bentonite is to repair particular damage. (Kong, Wu, Chai, & Arulrajah, 2017)



Figure 10. Calcium Bentonite Clay. Free Stock Media. (Hoychuk, 2023)

Self-Healing

GCLs can be damaged for a variety of reasons, including cuts from sharp objects, insufficient connections between sections, bentonite movement among GCLs caused by temperature, areas with insufficient bentonite, and lack of moisture, which causes clay cracks. Bentonite in GCLs is capable of covering these damage holes when compressed due to its high expansion capacity when hydrated. The swelling ability of bentonite is determined by parameters such as its mass and binding method; for example, needle-punched GCLs have a higher self-healing capacity than stitch-bonded GCLs. Additionally, higher bentonite content in the liner improves self-healing potential. (Kong, Wu, Chai, & Arulrajah, 2017)

Hydraulic Conductivity

The hydraulic properties of a GCL are influenced by the type and quality of clay utilized. Polymers, sodium carbonate,

lime, and other organic compounds are sometimes employed as additives to improve hydraulic qualities in clay with reduced bentonite levels. The amount of bentonite per unit area and its homogeneity additionally possess an impact on hydraulic performance. Greater bentonite per unit area generally results in decreased hydraulic conductivity. The exception is Geomembrane Supported-GCL, in which the geomembrane itself is the primary water barrier. (United States Environmental Protection Agency, 2001)

Shear Strength

The shear strength of Geosynthetic Clay Liners (GCLs) varies depending on the barrier system design. Because of the lack of reinforcement in the bentonite, GCLs lacking reinforcement, such as those connected with a chemical binder like in GM-GCL, have a relatively low shear force resistance. Reinforced GCLs, on the other hand, such as stitch-bonded and needle-punched GT-GCL, use penetrating fibers and threads for reinforcement, resulting in a significant increase in shear strength. Failure often happens at the point where the geotextile or geomembrane adheres to the bentonite for each individual GCL type. (Kong, Wu, Chai, & Arulrajah, 2017) (United States Environmental Protection Agency, 2001)

Applications of Geosynthetic Clay Liners

Landfills

Landfills play an important role in appropriate waste management, but improper handling can cause severe environmental damage. Landfills require appropriate containment measures to prevent the intrusion of solid and liquid waste into the soil such as leachate, hence protecting the surrounding groundwater and ecosystem. GCLs are used

in essential areas of landfill engineering such as foundation liners, surface liners, gas seals or caps, secondary containment, residual containment, waterproofing, groundwater protection, and the construction of vertical barriers. (Advanced Textiles Association, 2021)

Furthermore, because of their ease and speed of installation, GCLs provide advantages. Unlike compacted clay liner systems, GCL liner systems are less thick, allowing engineers to design landfills that maximize capacity while protecting local groundwater. Furthermore, GCLs are commercially viable in areas with limited access to clay. (United States Environmental Protection Agency, 2001)

Oil Industry

GCLs have shown to be a reliable alternative in the oil industry. They can be used as both primary and secondary barriers for containment, storage, runoff management, remediation covers, and artificial wetlands. The API establishes industry standards for designing and producing tanks that store oil, gasoline, and chemicals. To prevent damage from leaks or spills, the tanks must be lined at the bottom with a low-permeability solution, which makes GCLs an excellent choice for this purpose. GCLs are also used in this industry to create containment solutions for ponds. This technique also keeps sediment and debris out, preserving the pond's characteristics and uses. (US Fusion & Specialty Construction, 2021)

Water Resources

Geosynthetic Clay Liners are also utilized to provide containment in water management systems such as stormwater ponds, dams, groundwater protection and even recreational dams. The characteristics of GCLs allow for

water retainment that permit water levels to stay steady, prevent soil erosion, managing stormwater runoff, minimize seepage, prevent leakage of contaminants or leachate.

Advantages and Limitations of Geosynthetic Clay Liners.

Advantages

Geosynthetic Clay Liners typically boast the lowest permeability among various geosynthetic materials. The self-healing properties of bentonite allow for easy maintenance of GCLs over time. GCLs have a well-established track record in landfill settings, with widely understood design and installation considerations. Bentonite's ductile nature allows for deformation without cracking, particularly beneficial in scenarios like differential settlement. GCLs tend to have a reduced thickness that translates into more space for any activity such as waste or liquids containment or collection. The high demand for GCLs enables cost-effective production due to economies of scale and increased manufacturing efficiency. In comparison to traditional compacted clay liners, GCLs offer better results, easier installations and in most cases, lower costs.

Limitations

Bentonite's low shear strength makes GCLs' resistance to shear forces heavily reliant on the binding materials and processes employed. Incorrect installations, particularly in landfill management, can lead to hazardous situations such as leachate leaks, which may be challenging to detect promptly

Bentonite can desiccate in extremely dry conditions, leading to cracks that may increase the permeability of GCLs. In rare

cases, Bentonite may react with other chemicals, especially those from Municipal Solid Waste, posing potential challenges in certain environments.

Chapter 6: Exploring other Geosynthetics

Geonets

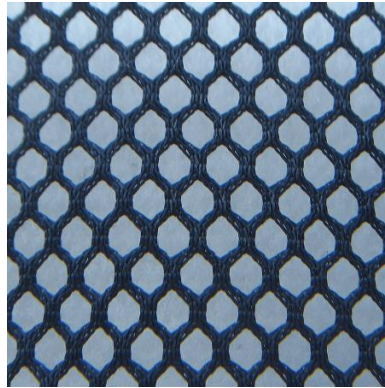


Figure 4. Biplanar Knitted Geonet. Public Domain Media. (Elkagye, 2009)

Geonets are created by continuously extruding polymeric ribs at acute angles, resulting in a net-like structure with large holes. Such Geonets are primarily intended for drainage and are made of different density polyethylene. Seaming them is more difficult than with Geomembranes; wire, staples, and threaded loops, are in occasions used for better manufacturing results. (Das & Sobhan, 2016)

There are two varieties of Geonets: biplanar Geonets, which are planar on both sides, commonly used in water drainage and retaining walls. Triplane Geonets, on the other hand, have an additional dimension that provides better reinforcement, therefore being suited for usage such as landfill liners that require improved stability. Given its emphasis on drainage, in-plane flow rates are an important design factor for Geonets. Geonets are useful in construction procedures because they can be used to replace granular

layers or to provide water drainage behind retaining walls. They also have a role in supporting retaining walls, distributing soil stress, preventing lateral displacement, and maintaining stability. (Earthshield, 2021)

Geonets are also used in the production of geocomposites. These are materials that incorporate Geonets and at least one geotextile. The geotextile, which acts as a filter and separator, allows liquid passage while inhibiting contaminants entry. Geotextiles frequently surround both sides of the drainage center, while the geonet itself serves as the drain component, allowing liquid to flow through its plane. (Geosynthetic Institute, 2012)

Geofoam



Figure 5. Geofoam Blocks. Free Stock Picture. (Vladyslav, 2023)

Geofoam, first introduced as a unique geosynthetic product category in 1992, includes both polymeric and non-polymeric foams used in a variety of geotechnical applications. Its functions extend beyond standard

geosynthetic materials, and it may either perform on its own or improve the properties and applications of other Geosynthetics, giving cost-effective solutions to a variety of geotechnical difficulties. Expanded Polystyrene (EPS) foam is the most well-known substance used in geofoams. (Insulation Company of America, 2023)

EPS foam, often known as Styrofoam™, offers qualities that make it an excellent choice for stabilizing slopes, retaining wall backfill, road foundations, and road insulation. EPS typically accounts for less than 1% of soil and rock weight and less than 10% of other lightweight fill materials, resulting in simple handling that assists in stabilization of unstable soil conditions and allows for more efficient project timetables. The nature of EPS provides a further benefit in that it can be cut and shaped to match individual project demands, making it appropriate for multiple applications. (Insulation Company of America, 2023)

Low density, insulation, high compressive strength, long-life outcomes, shorter construction time, lower costs, stability, minimal water absorption, and ease of handling are all advantages of geofoams. While geofoam has several advantages, it also has certain disadvantages. Its buoyancy produces uplift forces when submerged, destroying pavements unless placed above flood level or anchored. Also, its vulnerability to petroleum exposure, elevated costs compared to standard soil fill, the need for careful assessment of fire threats, and damage caused by insects are elements to take into consideration when designing and utilizing Geofoam material. (Gunawan, 2020)

Geocells



Figure 13. Geocells filled with sand. Free Stock Media. (Alecsps, 2023)

Geocells, also known as Cellular Confinement Systems in certain applications, are three-dimensional geosynthetic structures crafted from High-Density Polyethylene (HDPE) or Novel Polymeric Alloy (NPA). Their three-dimensional design allows these structures to be filled with materials like rock, sand, concrete, and gravel (Performance Footing, 2019). The honeycomb structure of geocells, when loaded with these materials, serves to enhance load distribution. Acting as walls, they reduce lateral movement and soil pressures while facilitating the vertical distribution of loads. Geocells are available in perforated and non-perforated types. Perforated geocells feature holes to improve air and water flow, while non-perforated variants are employed where the prevention of water and fluid flow is crucial.

The history of geocells traces back to the 1970s and 1980s when the U.S. Army Corps of Engineers sought innovative solutions for constructing roadways in soft grounds.

Geocells proved to be a faster and, in some cases, superior alternative to traditional materials like crushed stone and gravel (Webster & Watkins, 1977) . Over the years, various improvements have been made in geocells, including the use of recycled materials, grid strength optimization, and other modifications to enhance transportation and installation logistics. Geocells are often chosen for their ease of transportation and their capacity for volume variation, allowing for efficient shipping and on-site maneuverability. Beyond their original application in roadway construction, geocells have found diverse civil uses. They play a vital role in slope stabilization by creating three-dimensional soil walls with lateral restraints, preventing lateral movement and landslides. Geocells are effective in preventing erosion by confining soil or aggregate materials within their cellular structure, reducing erosion caused by wind and fluids. In water resources applications, the three-dimensional structure of geocells protects water bodies by blocking the lateral displacement of pollutants. Perforated geocells facilitate water flow, making them suitable for applications like green infrastructure. Additionally, geocells are applied to improve load distribution for small-sized systems built in soft soils, showcasing their versatility in various civil engineering projects. (BlueStone Supply, 2023)

Geotubes



*Figure 14. Geotubes in a coastal engineering project. Free Stock Media.
(Gouida, 2023)*

Geotubes are tubular constructions composed of geotextile materials that are used to confine, dewater, or stabilize diverse materials in construction, environmental, and infrastructure projects. Geotubes are typically created by carefully mixing and adding sand and water in a geotextile-lined container; following this fill, the sand is expected to settle at the bottom of the geotube and the majority of the used water drains. (Gateway Structure Sdn Bhd, 2023)

The use of geotubes for dewatering and confinement gained popularity in the 1980s. Researchers and engineers have modified the design and material composition of geotubes throughout the years, maximizing their performance for certain applications.

Geotubes have a wide range of applications in geotechnical and environmental engineering. They are mostly used in sludge dewatering procedures, where they effectively

separate water from semi-solid leftovers of wastewater treatment and industrial processes. Geotubes are also widely employed in coastline protection to prevent erosion, building projects for temporary retaining structures, and environmental cleanup to contain and isolate toxic materials. Their flexibility includes flood control, land reclamation, and delivering cost-effective infrastructure solutions. Most notably, geotubes have been used in situations where communities require appropriate storm surge protection, while at the same time combating erosion. In these cases, native soil is added into the geotubes with its respective water quantity and covered with this same soil for aesthetic purposes, resulting in the construction of small artificial dunes protected against erosion. (InTeGrate: PennState, University of New Orleans and Shippensburg University, 2022)

Trends and Future Directions in Geosynthetic Research and Applications

Several trends are shaping future research and applications of Geosynthetics. Notably, there's a growing focus on sustainable solutions, aligning with global environmental practices. Simultaneously, technological integration is gaining traction, enhancing performance through real-time monitoring and adaptive responses. Geosynthetics are pivotal in building resilient infrastructure to withstand climate change impacts, with ongoing research dedicated to developing enduring solutions.

Multifunctional materials are emerging, offering versatility in addressing engineering and environmental challenges. Global collaboration and standardization efforts are underway, ensuring consistent and reliable geosynthetic performance worldwide.

Despite slow adoption in sectors like mining and civil engineering, the industry acknowledges the need for change. Limited funding for large research projects creates opportunities for new, value-adding products. Key areas of focus include ecological considerations, product performance, and addressing cost, quality, and ease of use. (Advanced Textiles Association, 2022)

Opportunities from megatrends, such as autonomous vehicles and artificial intelligence, present avenues for geosynthetic applications. There's a reciprocal opportunity to apply solutions from these trends to enhance geosynthetic use.

Continuous research in geosynthetics is a testament to the dynamic nature of the field. A valuable repository for such ongoing endeavors is the ASCE Library, where a wealth of geosynthetics research is readily available. Specifically, the "Geosynthetics Research and Development in Progress" (<https://ascelibrary.org/doi/book/10.1061/9780784407820>) hosts a collection of 69 papers delving into various aspects of geosynthetics. This curated resource provides insights into the latest advancements, innovations, and ongoing projects, serving as a focal point for researchers, engineers, and industry professionals keen on staying abreast of the evolving landscape of geosynthetics research.

In summary, the future of geosynthetics involves sustainability, technological integration, climate resilience, global collaboration, and adaptation to megatrend solutions. As the industry navigates challenges and embraces opportunities, geosynthetics are catalysts for transformative change in engineering, construction, and environmental practices worldwide.

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