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Stabilization of the soil by geosynthetics techniques

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Abstract

Geosynthetics are adaptable materials utilized to strengthening the different type of soil and are regarded as an innovative, efficient, and cost-effective solution for various engineering applications in construction. This document examines the various uses of geosynthetics, such as barriers in earth dams, stabilization of embankments on weak foundations, decreasing earth pressures behind retaining structures, liner systems for landfills, filtration systems, drainage for pavements, enhancing stability on steep slopes, and reinforcing shallow foundations. Various kinds of geosynthetic materials can be employed for soil reinforcement, including geotextiles, geomembranes, geogrids, geocomposites, geofibers, geobags, geopipes, and geofoam, to improve their adaptability. A primary emphasis is on reinforcing soil to boost stability, minimize erosion, and improve drainage. The use of geosynthetics is crucial for enhancing soil strength to ensure it is appropriate for subgrade material, embankments, slopes, foundations, and earthen dams. The results of this review are important for geotechnical engineers and showed that using various type of geosynthetics enhanced load-bearing ability, minimized deformation in pavement structures, increasing strong shear resistance and reduced seepage in containment uses. Also the literature review explained improved tensile properties and the durability of stabilized soft soil. So it feeds construction experts, providing creative, sustainable, and cost-effective solutions to engineering problems.

Keywords: *geogrid, geocell, economical solution, soil reinforcement.*

1. Introduction

Geosynthetic materials have emerged as cutting-edge solutions for enhancing soil stability and minimizing soil subsidence. Various forms of geosynthetics, such as geotextiles, geogrids, and geomembranes, bolster stability, mitigate erosion, and strengthen drainage in soil systems [1]. Studies employing triaxial compression and single-plane shear tests have shown the efficacy of geosynthetics in reinforcing soil across different loading scenarios [2]. The overall behavior of geosynthetics-reinforced pile-supported embankments is influenced by the stiffness of geosynthetics, interface friction, and layer positioning [3]. The three primary advantages of geosynthetics in soil reinforcement are the construction of embankments on weak foundations, the stabilization of steep slopes, and the alleviation of earth pressures behind retaining walls [4]. These materials provide benefits compared to conventional techniques, including enhanced reliability, reduced construction duration, and compatibility with challenging soil conditions [5]. Geosynthetics were created to tackle the difficulties presented by traditional methods employing standard materials. They ultimately became essential for numerous construction uses [6]. The origin of geosynthetics arose from the necessity for efficient soil stabilization, erosion prevention, and safeguarding the environment. Notable advancements took place in geotextiles, geomembranes, geogrids, and various other geosynthetic materials to address these requirements [7, 8]. Issues related to conventional construction methods are linked to the evolution of geosynthetics. Problems like unstable slopes, inadequate drainage, and erosion led engineers to find creative solutions. The significance of geosynthetics is increasing to fulfill engineering requirements. These resources currently encompass landfill liners, earthen structures, drainage systems for pavement, stability of slopes, and shallow foundations [9]. These materials are vital resources for contemporary construction experts as they are adaptable, long-lasting, and eco-friendly. Lately, scientists have been concentrating on developing sustainable geosynthetic materials that reduce environmental impacts by investigating biodegradable geotextiles and other environmentally friendly options to foster a more sustainable construction sector [10].

Scientists are exploring novel reinforcement methods to enhance the stability and load-bearing strength of structures, including advanced geogrids and geofibers. Enhancing climate change resilience is a primary objective of studies that could be advanced through the use of geosynthetics. Research is examining how geosynthetics could aid in coastal defense, flood control, and enhancing infrastructure resilience to climate change. Clay liners, a combination of clay and geotextile, attract considerable attention from researchers for soil reinforcement due to their enhanced durability and impermeability[11].

2.The benefits of using geosynthetics as an alternative soil stabilization technique.

Geosynthetics play a crucial role in promoting environmental sustainability in engineering and construction, particularly in soil stabilization. These substances may enhance soil strength and reduce erosion. They have been used for landfill liners and drainage systems, which help prevent pollution and improve waste management.

2.1 Increased Soil Strength with Geotextiles.

Woven and non-woven geotextiles reinforce soil and increase its strength. The depth of geotextile affects the CBR of subgrade soils. The effect of woven geotextiles is more than that of the non-woven types, leading to thinner pavement and lower construction costs [12]. Geotextiles are consider high-performance materials which used in different geotechnical problems [14]. The most applications of the geotextile included reinforcing soil, filtration under roads, and soil stabilization [15]. Recently, geotextiles are usually prepared of synthetic fibers utilized to improve soils in different applictions [16].

2.2 Geosynthetics for Soil Stability and Sustainability.

The effect of geosynthetics is not limited to increasing the bearing capacity of soil; it also reduces the need for natural resources, making it a sustainable material [12]. Geosynthetics exhibited strong shear resistance and reduced seepage in containment uses [22] and minimized seepage in tailings pond bases and enhanced environmental safety[23] and [22].

2.3 Geosynthetics for Flexible Pavement Reinforcement.

Geosynthetics reduced vertical and dynamic stresses reached the pavement base up to 66% and 72% respectively [13]. This improvement extends the lifespan of the base layers and increases the rutting resistance. Geosynthetics enhanced soil confinement and improved the structural performance of transport infrastructure [19] and enhanced load-bearing ability and minimized deformation in pavement structures [20]. Geosynthetics enhanced the strength of expansive soil by raising the CBR and peak loading value, particularly when applied in multiple layers [18].

3.Geosynthetics material properties.

The geosynthetics' properties are significant for assessing the effectiveness and appropriateness of the material for different uses in civil and geotechnical engineering. The key properties of geosynthetics:

3.1 Physical properties

The physical properties of geosynthetics depend on the type and function of the geosynthetics, since there are various types of geosynthetics, such as geotextile, geogrid, geomembrane, geocell, and many others. The key physical properties of geosynthetics could mainly include mass per unit area (g/m^2), which indicates the density, thickness (mm), which affects the strength and filtration capacity of the material, the opening size, which affects the filtration and soil retention capability, porosity, which is important for filtration and drainage, specific gravity, which helps predicting the behavior of the material in water or under loading, and flexibility, which express the ease of utilizing and installing the geosynthetics.

3.2 Mechanical properties.

The mechanicalproperties refer to the behavior of the material under various physical stresses. Geosynthetics include geotextiles, geomembranes, geogrids, geonets, and geocomposites, and their mechanical properties are significant to specify their suitability for reinforcement, filtration, drainage, and containment. The key mechanical properties of geosynthetics include tensile strength, which is the maximum stress the geosynthetics can withstand without being pulled or stretched, tear strength, which indicates the resistance of the material to tearing when a flaw or cut exists, and this is significant for durability during installation, puncture resistance represents the ability of the material to resist penetration by a sharp item, burst strength, which represent the ability of the material to withstand the rupture when exposure to a uniform pressure from one side, creep resistance, which represents how the material not to deform under constant loading over time, stiffeness, which is the ratio of stress to strain and it is significant to evaluate the extent to which the material will deform when loading is applied.

3.3 Durability properties.

Durability expresses the ability of the material to perform under various mechanical, chemical, and environmental circumstances over time. It is significant since most geosynthetics are needed for long-term applications such as landfills, embankments, and roads. The key durability properties of geosynthetics include UV resistance, which is significant for the geosynthetics to be used above ground since UV exposure can lead to polymer breakdown, oxidation resistance, which expresses the ability of geosynthetics to withstand chemical breakdown when exposed to oxygen, chemical resistance, which is the ability of geosynthetics to resist changes when exposed to chemicals in the environment or soil, biological resistance, which is mainly the ability of the material to resist bacteria and fungi attack, thermal stability that makes it maintain a structural performance and integrity under high or low temperatures, and abrasion resistance, which is the ability of geosynthetics to resist surface damage due to friction with soil particles.

3.4 Hydraulic properties.

The hydraulic properties refer to the ability of geosynthetics to interact with water, which is vital for filtration, drainage, and containment. The hydraulic properties depend on the type of geosynthetics, such as geotextile, geocell, geogrid, or geomembrane. The key hydraulic properties of geosynthetics include permittivity, which describes the ability of the material to allow water to move perpendicularly through its plane. It is significant to measure the ease with which water passes through the thickness of the geosynthetics. Transmissivity describes the ability of water to move within the plane of the geosynthetics. Apparent opening size describes the largest soil particle to pass through the geosynthetics. Permeability describes the amount of water that flows through the geosynthetics per unit area in a specific time. Clogging resistance is the ability of the geosynthetics to resist clogging when soil particles pass through it over time. Hydraulic conductivity is the ease with which water flows through the geosynthetics, and it significantly affects the drainage ability and flow rates.

4. Types and functions of geosynthetics.

Geosynthetics are utilized in geotechnical engineering to reinforce soil and improve soil properties, as well as help in drainage or filtration. There are many types of geosynthetics. In this study, seven main types will be discussed.

4.1 Geotextiles.

Geotextiles are used in different geotechnical applications as high-performance materials [14]. The functions of the geotextile include soil reinforcement, filtration, drainage, and soil stabilization [15]. Recently, geotextiles are usually made of synthetic fibers, but the idea is connected to that when natural fibers were utilized to improve soils [16]. More environmentally friendly geotextiles using natural fibres have recently gained more interest, as they are more economical, have comparable mechanical properties, and offer biodegradability [17]. Geotextiles have many applications for transportation or liquid containment systems due to the versatility of these items, and there is an interest in innovating multifunction geotextile solutions [16].

Table1: Summarized literature review of geotextiles.

resource	Area of work	Function	Findings
[18]	subgrade	Reinforcement	Geotextile enhanced the strength of expansive soil by raising the CBR and peak loading value, particularly when applied in multiple layers.
[12]	pavement subgrade	Soil stabilization	Woven geotextiles enhance CBR values and boost pavement efficiency, leading to decreased pavement thickness and lower construction expenses.

[15]	silt soil	Drainage and reinforcement	Wicking geotextiles enhanced the mechanical properties and deformation resistance of silty soil when subjected to loading conditions.
[16]	environmental applications	Filtration and separation	Geotextiles offer efficient filtration, separation, and environmental safeguarding in drainage and containment solutions.
[17]	erosion control	Sustainability	Natural-fiber geotextiles provided cost-effective and biodegradable options for mitigating soil erosion and degradation.

4.2 Geogrids.

Geogrids are polymer-based materials mainly used in transportation and soil reinforcement [19]. There are different types of geogrids depending on the configuration, such as triaxial, biaxial, and uniaxial, and each of these has a different loading capacity, which could be used for different applications. The performance of geogrids depends on many factors such as their geometry and structure, the mechanical properties, and the interactions with the soil [20]. The main use of geogrids is for road subgrade, since they increase the bearing capacity of subgrade, durability, and reduce the aggregate thickness [21].

Table 2: Summarized literature review of geogrids.

resource	Area of work	Function	Findings
[19]	road subgrade	Reinforcement	Polymer geogrids enhanced soil confinement and improved the structural performance of transport infrastructure.
[20]	transportation engineering	Load distribution	Geogrid reinforcement enhanced load-bearing ability and minimized deformation in pavement structures.
[21]	soft clay subgrade	Bearing capacity improvement	Triaxial geogrids considerably enhanced the load-bearing capacity of unpaved roads on soft clayey soils.

4.3 Geomembranes.

Geomembranes are thin flexible sheets made of polymeric materials used in civil and environmental engineering for waterproofing and containment applications due to their low permeability [22, 23]. There are three types of geomembranes regarding the nature of plastic material: elastomeric, thermoplastic, and bituminous [24]. Each of these types has different properties and assembly techniques. High-density polyethylene has been used widely for more than 40 years due to its durability with long-term performance. Several factors could affect the geomembrane's aging, which include temperature changes and some chemicals [25]. A method for selecting suitable geomembranes has been developed to ensure tough design requirements and long-term performance, considering factors like immersion in simulated leachate [26].

Table 3: Summarized literature review of geomembranes.

resource	Area of work	Function	Findings
[22]	containment systems	Seepage control	Geomembranes exhibited strong shear resistance and reduced seepage in containment uses.
[23]	tailings ponds	Waterproofing	Geomembrane liners minimized seepage in tailings pond bases and enhanced environmental safety.

[25]	waste system	Durability	HDPE geomembranes demonstrated outstanding long-term resilience when exposed to environmental conditions.

4.4 Geofibers.

Natural or synthetic geofibers have been utilized for soil stabilization as an economical and environmentally friendly technique to improve geotechnical properties [27]. The properties that geofibers improve are unconfined compressive strength, California bearing ratio, and reducing volume changes. Fibres, when added to soil, work as tension members, which leads to an improvement in the engineering properties of the soil [28]. Natural fibres such as sawdust are getting more popular to be used for soil stabilization due to the low cost, and can be recycled waste materials [29]. The efficiency of geofibers depends on several factors such as the quantity, fiber length, distribution, and length [30].

Table 4: Summarized literature review of geofibers.

resource	Area of work	Function	Findings
[27]	soil stabilization	Reinforcement	Natural and synthetic fibers decreased soil deformation and enhanced unconfined compressive strength.
[28]	soft soil	Tensile reinforcement	Geofibers have improved tensile properties and the durability of stabilized soft soils.
[29]	expansive soil	Friendly stabilization	Sawdust fibers enhance soil characteristics and offer an eco-friendly and economical solution for stabilization materials.

4.5 Geocells.

Geocells are three-dimensional cellular confinement systems, honeycomb-like structures utilized for soil reinforcement [31]. They are made of high-density polyethylene and utilized for foundations, roads, railways, and retaining structures. They reduced the settlement and increased the bearing capacity by providing lateral confinement for soil [32]. Geocells reinforcement mainly improves soil stability for shallow slopes and load-bearing capacity in various geotechnical applications [31]. Several factors affect geocell performance, such as depth of geocell placement, cell size, height, width, and soil unit weight [33]. Smaller geocells are more effective than the large ones for controlling erosion and stabilizing slopes. The most effective depth for the geocells is at (0.3-0.5) B.

Table 5: Summarized literature review of geocells.

resource	Area of work	Function	Findings
[31]	Slope stabilization	Soil confinement and reinforcement	Geocells increased shallow slope stability and increased load-bearing capacity in various geotechnical issues by confining soil laterally.
[32]	Foundations and transportation infrastructure	Soil bearing capacity improvement	Geocells resulted in decreased settlement and enhanced bearing capacity of soils beneath foundations, roads, railways, and retaining walls.
[33]	Geocell-reinforced soil beds	Performance optimization	The performance of geocells was influenced by the dimensions of the cells, the depth at which they were placed, and

			the soil's unit weight. Smaller geocells provide improved erosion control and enhance slope stabilization.

4.6 Geobags.

Geobags are a geosynthetic material effective for soil stabilization and erosion mitigation in different applications. They are considered an economical and environmentally friendly solution for slope stabilization and erosion protection [34]. Geobags are also significantly useful for riverbank protection, demonstrating their ability to retain soil [35]. There are various types of geobags depending on their size: small, medium, and large. The use of each one depends on the condition of the work. Small ones are used for temporary works, medium ones for emergency works, and large geobags are for permanent works.

Table 6: Summarized literature review of geobags.

resource	Area of work	Function	Findings
[34]	riverbank protection	Erosion control	Geobags effectively stabilized riverbanks and significantly decreased erosion during hydraulic loading stages.
[35]	slope protection	Soil retention	Geobags offered cost-effective and eco-friendly safeguarding for riverbanks and embankments.

4.7 Geocomposite.

Geocomposites are innovative materials that combine two geosynthetic materials to to solve complex engineering problems efficiently, such as soil strength, durability, environmental benefits, stability, and protection against erosion. These materials are mainly effective in mitigating the challenges posed by soft soils, which can lead to issues like cracking and excessive settlement. For example, a geogrid-geotextile geocomposite creates a stable working surface on soft soils, mitigating the expansion of the facility [36]. There are various types of geocomposites depending on their required functions. Geotextile and geomembrane are used for environmental protection in landfill containment. Geotextile and geonet are used for landfills and under-road drainage. Soil reinforcement and separation, geotextile and geogrid are used.

5. Conclusion.

Geosynthetics serve various main functions in civil engineering and environmental applications and especially geotechnical engineering. Their versatility makes them significant components in mitigating multiple challenges.
This review revealed various kinds of geosynthetics, such as geotextiles, geogrids, geomembranes, geofibers, geocells, geobags, and geocomposites. These are crucial for soil stabilization, structural reinforcement, filtration, drainage, erosion control, and environmental protection. Geosynthetics are extremely efficient for infrastructure developments such as roads, embankments, retaining walls, landfills, shallow foundations, rail systems, and riverbank protection systems.
The evaluation indicated several points that are taken into account:

1. The geotextiles increase subgrade strength, California Bearing Ratio (CBR) values, and decrease pavement thickness and construction expenses, making them an economical choice.
2. The geogridswere found improve load distribution, load-bearing capacity, and pavement durability, particularly in soft soil environments.
3. Geomembranes offer effective waterproofing and leakage prevention for containment systems and waste management facilities due to their low permeability and long-lasting durability.

4. Geofibers contribute to sustainable soil stabilization by enhancing tensile strength and minimizing soil deformation while utilizing recyclable and eco-friendly materials.

5. Geocells were found to offer effective lateral confinement, greatly improving bearing capacity and minimizing settlement under foundations and slope stabilization systems.

6. Geobags and geocomposites provide effective and cost-efficient solutions for reducing erosion, enhancing drainage, and improving weak soils.

7. The geosynthetics increase the service life of infrastructure, minimize maintenance requirements and reduce the consumption of traditional construction materials. Their ability to improve drainage and reduce erosion further improves environmental protection against climate-related.

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