CHAPTER 43

A Study on Impact of Geosynthetic Applications in Construction Projects

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ABSTRACT

The infrastructure projects such as highways, railways, and other critical or mega structures poses challenges with respect to the ground condition. Most of the projects necessitates the deep foundation or ground improvement to overcome the problems associated with unfavourable ground conditions such as weak, expansive, or soft soils. Geosynthetics have been the most important innovation in the field of ground improvement. This includes Geotextile, Geogrids, Geonets, Geocells, Geostrips, Geomats & Geomembranes and each has their own purpose and function. They often outperform traditional solutions, enabling longer lasting support at lower material cost. The present work includes study of geosynthetics material types and their application principles in construction industry. The study will focus on evaluation of design efficiency, construction methodology, environmental impact, cost and time savings by usage of geosynthetic materials particularly geotextile and geocell. The key findings of past studies such as degree of ground improvement, behaviour, sustainability, project cost & time saving factors are discussed.

Keywords: Geosynthetics, Geotextile, Geocell, application, benefits, sustainability.

1.0 Introduction

Infrastructure construction including Bridge, Highway, Embankment and Foundation is greatly affected by soil conditions present in the area. Different types of Soil exist in nature with various compositions and different Engineering properties. Some areas have insufficient enough soil strength for the design loads required of an Infrastructure project due to weak soil conditions. Weak soils often produce low bearing capacity and therefore excessive compressibility and problems such as swelling. New developments in Geotechnical Engineering continue to help engineers achieve both greater stability and sustainability of their constructed Assets.

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Geosynthetic materials are one example of how Geotechnical Engineers are bringing Sustainable solutions to the Planning/Design Phases of their Infrastructure construction projects. The usage of geosynthetic materials in geotechnical engineering can significantly improve sustainability at the planning and design stage of infrastructure construction projects. Geosynthetic materials such as an alternative to traditional ground improvement materials are generally Geotextile, Geogrids, Geonets, Geocells, Geostrips, Geomats & Geomembranes. By implementing these materials at the planning and design stages, engineers can increase overall strength of structures and long-term sustainability. The present review was aimed to develop an understanding of how geosynthetic materials geocell & geotextile enabled structures significantly improve their overall bearing capacity, their design aspects for achieving desired bearing capacity, sustainability and project performance are covered via systematic literature review.

2.0 Literature Review

The incorporation of geosynthetic materials signifies a meaningful change in ground improvement technology, tackling the fundamental challenges in natural soil characteristics in extensive infrastructure endeavours. This review integrates significant insights from the existing literature, concentrating on the practical uses, design efficiencies, and sustainability advantages of geosynthetics specifically highlighting geocells and geotextiles in relation to ground enhancement

2.1 Characterization and mechanical evaluation

Standardized testing is essential to ensure that geosynthetics meet the physical and mechanical requirements of a project.

2.1.1 Physical property testing

- *Specific Gravity*: Measured via ASTM D792 to determine density consistency.
- *Mass per Unit Area*: Evaluated under ASTM D5261, typically reported in grams per square meter (g/m^2).
- *Thickness*: Determined by ASTM D5199 under a standard pressure of 2 kPa.
- *Flexural Rigidity (Stiffness)*: Assessed by measuring the overhang distance on an inclined plane to determine how the fabric behaves during deployment over soft subgrades. *(Rajagopal, 2013)*

2.1.2 Mechanical performance metrics

- *Tensile Strength*: The Wide Width Tensile Test (ASTM D4595) provides accurate force-per-unit-width and peak strain data. Index tests like the Grab Tension Test (ASTM D4632) simulate localized stretching from construction stresses.

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- *Puncture Resistance*: Evaluated through static methods (ASTM D4833), the CBR Puncture Test (using a 50 mm plunger), and dynamic "cone drop" tests to simulate impact from falling stones.
- *Seam and Burst Strength*: Seam efficiency ensures structural continuity, while the Mullen Burst test (ASTM D3786) measures resistance to multidirectional pressure. *(Rajagopal, 2013)*

2.2 Mechanics of three-dimensional cellular confinement

Geocells gives additional planar reinforcement to three-dimensional confinement effect of geocells.

2.2.1 Confinement mechanisms

Geocells can control how much lateral movement of fill can occur due to the tension applied to the geocell walls (known as hoop tension) *(Rimoldi & Brusa, 2022)*. The geocell structure provides an increase in the vertical movement of soil when placed in the geocell structure, due to increased confining pressure on the soil by lateral geocell walls. Therefore, as more soil is placed in the geocell mattress, the shear strength and elastic modulus will increase proportionally to the amount of soil confined in the mattress *(Han, et.al., 2010)* Geocell mattresses can mitigate lateral movement of soft clay materials at the foundation level by providing a semi-rigid pavement support system.

2.2.2 Stress distribution and bearing capacity

The "slab effect" created by geocells broadens the dispersion angle of vertical forces, therefore; the overall vertical forces exerted on the subgrade is reduced by 20% to 50% depending on the distance from the Load Application Centroid (Centre of Geocell structure). Additionally, the presence of geocells causes a re-direction of the Principal Stresses (i.e. the rotation of the Principal Stresses) in soil embankments which reduces the potential for slip circle failure and increases the bearing capacity factor N of a geocell mattress (approximately 5.14 - >7.0) *(Inti, et al., 2021)*.

3.0 Design and Methodology for Geocell Reinforcement

The *Han & Pokharel (1984)* method for unpaved roads modifies the Giroud & Han design Models for geocell reinforced roadways to accommodate the unique parameters of geocell, including Stiffness and Tensile Strength. Cumulative wheel loads and CBR from a repeated plate load tests were noted and used to create Cumulative Wheel Pass and CBR Data so that the Minimum Thickness Required for Geocell Layers can be calculated based on the requirements of Traffic *(Han, et al., 2011)*.

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3.1 Modulus improvement factor (MIF)

The MIF (EReinforced / EUn-Reinforced) determines the total stiffening benefit of each of reinforced material over an unreinforced material through calculations based upon their their modulus values. For very weak subgrades (10MPa) MIF values can reach 3.13 to 5.38. Field trials using Novel Polymeric Alloy (NPA) geocells have demonstrated MIF values as high as 2.75 to 2.84, enabling a 50% reduction in pavement thickness *(Kief et al., 2011)*.

3.2 Construction efficiency and technology

The way we design & construct (the construction methodology) changes drastically when deploying geosynthetics as opposed to using traditional materials, thereby removing the need to perform many heavy & slow constructions steps associated with using those traditional materials such as concrete and steel. Since geosynthetics are made of lightweight, flexible materials, they dramatically simplify logistical requirements and allow a manual handling of the materials in situations where heavy equipment (such as large cranes and earth moving machines) would be needed to transport the traditional materials.

3.3 Digital applications in design

The adoption of specialized digital engineering tools has greatly contributed to the modernization of geosynthetic construction. The NAUE Geosynthetic Design Suite is one of the portals which functions as a comprehensive geotechnical software solution. It offers engineers a series of calculators aimed at optimizing infrastructure projects via accurate material modelling. By employing such tools, projects are no longer dictated by "design conservatism" but rather backed by performance data, which in turn guarantees their safety, cost efficiency, and sustainability. The main modules consist of:

3.3.1 Naue platform (working platform design)

This software tool allows for the quick creation of temporary working surfaces in soft subgrade soils applying the well-established BR470 design method and Naue's secret "Hybrid Method." *(Khansari et al., 2023)*. The system not only takes into account the particular loads related to the construction equipment (for instance, piling rigs or cranes) and the soil parameters but also calculates the most suitable thickness for the base course. This accuracy avoids the risk of excessive deformation or structural failure, which are serious safety hazards in such weak cohesive soil conditions *(Naue_Adm_Web. 2025a, October 22)*.

3.3.2 Naue UnpavedRoad & SecuCalc

By means of the adapted Giroud-Han approach, these calculators can create the temporary access and haul roads ideally designed. Performance data for Secugrid® geogrids

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and Combigrid® geocomposites are incorporated in the software, thus enabling the engineers to model the traffic movement with the "wheel wandering" effect, thereby realizing more accurate load distribution and cutting the base course thickness by as much as 50% *(Naue_Adm_Web. 2025b, October 22).*

3.3.3 Naue VeneerReinforcement

The specialized tool in question evaluates the stability of stratified thin systems not only during the construction phase but also in the final stage. This is of utmost importance in protecting the environment, where, for instance, landfill caps and mining closure projects rely on the stability of steep slopes *(Naue_Adm_Web. 2025c, October)*.

4.0 Sustainability and Circular Economy

Geosynthetics facilitate the use of marginal materials and reduce the overall environmental footprint of civil works.

4.1 Stabilization of recycled asphalt pavement (RAP)

RAP is susceptible to creep and permanent deformation due to asphalt content. Geocell confinement significantly reduces this deformation. At a 75 mm rut threshold, NPA geocells can improve the service life of a 0.30 m RAP base by a factor of 19.4 compared to an unreinforced base of the same thickness (Pokharel et al., 2010).

4.2 Life cycle assessment (LCA) data for reinforced earth wall

Designers can utilize life cycle assessment (LCA) to calculate a score that will help them to determine which type of design (traditional vs geosynthetic) should be utilized. Following case studies illustrate the quantified environmental benefits of substituting conventional mineral and concrete materials with geosynthetics (Stucki et al., 2011).

A comparative examination of a one running metre of the three-metre-high wall for a 100-year lifespan was conducted by the E.A.G.M., comparing to Geosynthetic Reinforced Soil Wall (G.R.R.W.), which is made up of polyethylene and PET woven geogrids having a long-term strength of 14kN/m. The table below indicates all the specific information for both Types of Walls and the building materials for the GRRW that would be constructed out of site fill, wall embankment(s) and as a finishing cap over the G.R.R.W. To assure that the construction of the GRRW conforms to CRRW, an 80 cm thick gravel drainage will be used for both types of Retaining Walls, utilising rounded stones for the drainage medium behind the Concrete Lining.

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Table 1: Typical Comparison of Concrete and Reinforced Soil Retaining Wall

Item	Unit	Concrete Wall	Reinforced Soil Wall
Concrete	m^3/m	1.60	-
Lean mix concrete	m^3/m	0.24	-
Structural concrete	m^3/m	2.10	3.31
Reinforcing steel	kg/m	153.00	-
Gravel	t/m	4.30	4.30
Bitumen	kg/m	2.84	-
Three layered laminated board	m^3/m	0.01	-
Geosynthetic	m^2/m	-	39.20
Polystyrene foam slab	kg/m	0.25	-
Polyethylene	kg/m	1.74	2.02
Diesel in building machine	MJ/m	11.60	53.90
Transport, lorry	tkm/m	701.00	265.00
Transport, freight, rail	tkm/m	33.20	6.90
Land use	m^2/m	1.00	0.60
NMVOC	g/m	20.00	-

Source: Stucki et al., 2011

Table 2: Typical Quantity for Production of 1kg Geosynthetic Layer in Slope retention

Items	Unit	Value
Raw materials	kg/kg	1.02
Water	kg/kg	0.86
Lubricating oil	kg/kg	7.30×10^{-5}
Electricity	kWh/kg	0.73
Thermal energy	MJ/kg	1.24
Fuel for forklifts	MJ/kg	0.13
Building hall	m^2/kg	6.32×10^{-6}

Source: Stucki et al., 2011

The environmental assessment of 1 m of retained earth for every 3m of height and across its full life cycle including construction, disposal, and provision of raw materials was carried out. *(Stucki et al., 2011)*.

From the below figures, compared to the other ground improvement & slope retention techniques the geosynthetic reinforced wall replaces the use of concrete and reinforcing steel, which will benefit 63% & 87% lower environment emissions.

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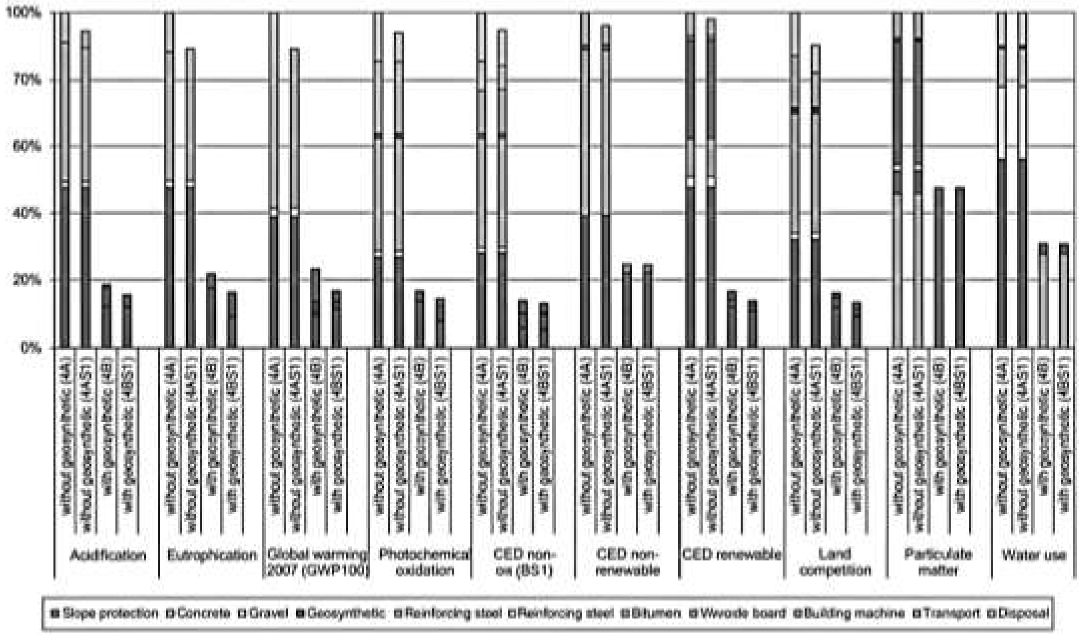
Figure 1: Typical E.I.A. Comparison of Conventional and Reinforced Retaining Wall



Source: Stucki et al., 2011

5.0 Economic Evaluation and Project Efficiency

The economic benefits of geosynthetic materials are driven by material savings as compared traditional ground improvement methods and accelerated construction schedules.

Material Reduction: Geogrid reinforcement allows for a 30% to 50% reduction in gravel thickness. Geocell reinforced retaining structure shows that these structures have ability to tolerate large settlements with the minimal use of filling material. Pavement cost savings typically range from 14% to 24% *(Aanand jain, 2016)*.

Retaining Structures: GRRW solutions offer approximately 30% cost savings over traditional R.C.C. walls by replacing steel and cement with polymeric reinforcements and on-site soil *(Aanand jain, 2016)*.

Bridge Approaches: Utilizing geosynthetic reinforcement at bridge approaches can reduce the number of required grade beam piles by 40% to 50% *(Aanand jain, 2016)*.

6.0 Conclusion

The comprehensive review confirms that geosynthetic applications in civil engineering provide a superior alternative to design sustainable solutions in geotechnical

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engineering. By leveraging the unique three-dimensional confinement mechanism of rotating principal stresses, geosynthetics enhances the constructability of micro-mega structures on terrain, hills & slopes previously considered unsuitable. The significant improvements in bearing capacity in geosynthetic enabled structures, the 30% average cost savings, and the 80% reduction in carbon emissions—coupled with digital design tools like the Naue Portal enables the geosynthetics as a core component of sustainable, modern civil infrastructure design to everyone.

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