High-Strength Geogrids for Enhanced Ground Improvement: Design Considerations

M. Mushaathoni[1], S. Naidoo[2]

[1]Maccaferri, Johannesburg, Gauteng, m.mushaathoni@maccaferri.com
[2]Maccaferri, Johannesburg, Gauteng, s.naidoo@maccaferri.com

Abstract

The increasing scarcity of usable land due to various global factors necessitates using advanced soil improvement techniques (Das et al., 2021). These techniques aim to transform unsuitable soil into engineered soil with the desired properties for civil engineering applications. Soil is a natural resource used as a construction material, however, its performance as a construction material must be checked to determine its efficiency for engineering applications (Das et al., 2021). As the scarcity of suitable construction sites arises, one will inevitably build on problematic soils (Muthukkumaran et al., 2022). This paper explores the growing use of high-strength geogrids as a sustainable and effective approach for ground improvement in civil engineering projects and addresses important design considerations for integrating high-strength geogrids into engineering projects according to SANS 207:2011. It further highlights how high-strength geogrids improve soil properties, enhancing the stability and performance of structures including the benefits associated with the use of these geogrids, offering a geosynthetic alternative to traditional ground improvement methods.

Keywords: *High-Strength Geogrids, Ground Improvement, Stability, Geosynthetics, Soil*

1 Introduction

In terms of soil mechanics, soil effectively resists compressive forces but exhibits a significantly lower capacity to withstand tensile stresses. This necessitates the use of geosynthetics such as geogrids whenever tensional resistance is crucial (Naidoo and Jacob, 2021). Ground improvement techniques aim to enhance the mechanical properties of soil to align with the specific requirements of a project while ensuring the stability and performance of civil engineering infrastructure (Muthukkumaran et al., 2022).

One approach to address the scarcity of suitable land for construction involves transforming unsuitable soils into engineered soils with enhanced mechanical properties. However, natural soil often exhibits limitations in its ability to meet the demands of civil engineering projects (Das et al., 2021). Historically, soil improvement has relied on traditional methods which involve piling, soil replacement, stone columns, and soil mixing. These methods are effective; however, they can be expensive and time-consuming (Jacob and Naidoo, 2023).

2 Defining a High-Strength Geogrid

High-strength geogrids are emerging as a viable option for enhancing the overall performance of ground improvement projects. These geogrids can improve the soil-bearing capacity and absorb distributed loads more uniformly, widening the load distribution area which showcases a significant improvement in the overall stability of the ground (Jacob and Naidoo, 2023). Koerner (2012), defines a geogrid as a geosynthetic material consisting of parallel sets of intersecting ribs connected to form suitably sized apertures that allow strike-through of surrounding soils, stone, or other geotechnical material. The primary mechanism by which geogrids improve soil performance is through confinement. A robust grid configuration confines the soil particles surrounding it, restricting their lateral movement, and enhancing the overall shear strength of the soil mass. Additionally, geogrids promote interlocking between the soil particles. The grid's apertures allow soil particles to become lodged within the openings, which further contributes to the improvement of soil stability (Koerner, 2012). High-strength geogrids are designed for challenging applications in geotechnical, mining, and civil engineering fields. These applications typically involve high loads, seismic conditions, or harsh ground conditions. The geogrid offers several key features that make it a suitable option for these demanding situations such as a long-term design life and durable structural reinforcement (Koerner, 2012).

2.1 The Application of High-Strength Geogrids

Designers can achieve better performance, stability, and cost-effectiveness of ground improvement projects by incorporating geogrids. The term "stability" is often used to differentiate between situations where lateral and vertical deformations are constrained and scenarios where tensile forces ensure force balance, effectively reinforcing the structure (Mulabdić et al., 2018). The geogrids improve load transfer to piles, enhancing stability and reducing settlements. This allows for wider spacing between piles, smaller pile caps, and potentially fewer piles, leading to both cost and time savings in construction. They can be further used to control lateral shear forces and minimize differential settlements in embankments. Geogrids can be used to reinforce walls where they help create stable retaining walls by reinforcing the soil used as backfill, improving its load-bearing capacity (Jacob and Naidoo, 2023). High-strength geogrids are used in a variety of scenarios, such as embankment reinforcement which helps control settlement, prevents sliding of the base, and protects embankments from internal and global failures (SANS 207:2011, 2011).

2.2 Benefits of High-Strength Geogrids

High-strength geogrids offer a range of benefits. They absorb and distribute imposed loads more uniformly across the reinforced area resulting in a reduction of settlement and a significant amount of improvement in the overall stability and performance of the reinforced soil. The grid configuration offers additional support and prevents excessive lateral movement within the soil mass. Additionally, compared to some traditional methods, geogrids can offer a more cost-efficient solution for ground improvement projects, and are often lightweight and relatively easier to install which allows for steeper embankments on smaller footprints (Jacob and Naidoo, 2023). They also prevent catastrophic collapse and minimize surface deformations in areas susceptible to voids (SANS 207:2011, 2011). The widespread adoption of geogrids in civil engineering stems from their effectiveness in soil reinforcement applications, a crucial function considering soil's inherent weakness in tension (Jacob and Naidoo, 2023). This includes their use in retaining walls, where geogrids enhance structural stability, and basal reinforcement, which improves foundation performance, demonstrating exceptional performance and reliability even in challenging scenarios (Zannoni, 2011). Figure 1 shows a high-strength geogrid commonly used in basal reinforcement applications.

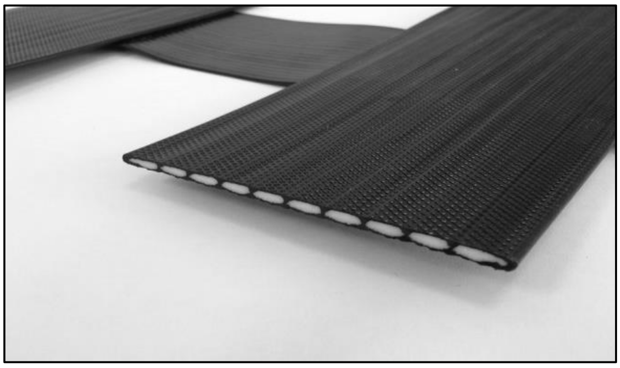

Figure 1: High-Strength Geogrid

3 Designing embankments over soft soils

When geogrids span weak zones in foundation soils, they provide support for vertical loads. Geogrids are sometimes used to enhance short- and immediate-term safety margins, especially for embankments constructed over weak cohesive foundation soils. Without reinforcement, embankments can become unstable before the foundation soil consolidates, potentially leading to lateral spreading failure. To prevent this, a geogrid can be added to the base of the embankment to help prevent lateral extrusion and spreading failures. The surface roughness, tensile strength, and axial tensile stiffness of the geogrid are crucial for transferring shear stresses away from the weak foundation soil. Basal reinforcement influences the shape of the failure surface, resulting in the reduction of the potential of shear failure in the fill of the embankment or foundation soil. Once the soil consolidates, the reinforcement becomes unnecessary. The design life of a geogrid is determined by the time needed for the foundation soil to consolidate, and its design strength is governed by the tension required to provide lateral or rotational stability for both the fill and foundation soil.

Geogrids offer a geosynthetic solution to prevent failures over soft soils by reinforcing the embankment and enhancing its overall stability. Geogrid interaction with soil is crucial for effective soil reinforcement. For embankment design, soil sliding along the geogrid surface and geogrid pullout from the soil needs to be considered. Factors like soil properties, interlocking, and reinforcement characteristics influence bond strength and load transfer. Soil and reinforcement properties, as well as environmental factors, affect the performance of reinforced soil. High-strength geogrids are necessary for aggressive fill environments to ensure durability and mechanical performance (Das et al., 2021).

SANS 207:2011 provides a framework for designing embankments using geogrids. Important design criteria include the calculation of external loads such as traffic loads to determine the required reinforcement capacity, understanding the properties of the soil (such as the shear strength parameters and drainage), properties of the geogrid (such as tensile strength and aperture size) and the geometry of the embankment (including height, slope angle, and base dimensions). The design process entails site investigation to determine the geotechnical properties of the founding material, selecting an appropriate analysis of the internal and external stability, and designing the geogrid layout to achieve optimal reinforcement. When designing according to SANS 207:2011, the soil properties, external loads, geometric data, and geogrid properties must be integrated to obtain a design output. This design output will specify the required geogrid type and amount, as well as the embankment geometry with optimized slope angles and height (SANS 207:2011, 2011). Constructing embankments on soft grounds presents significant challenges due to weak soils that cannot support the weight of the embankment which leads to probable failures highlighted below:

Lateral spreading:	This is the outward pushing of soft soil under the embankment due to its weight.
Foundation extrusion:	This is when weak soil gets squeezed upwards into the embankment.
Rotational instability:	This is when the entire embankment rotates around a point due to uneven loading or a weak foundation, which leads to a complete collapse.

3.1 Limit State Design Considerations for High-Strength Geogrid Reinforced Embankments

The ultimate limit state (ULS) is related to the collapse or other forms of structural failure, while serviceability limit states (SLS) are reached if the magnitude of deformation exceeds specified limits or if the serviceability of the structure is compromised (SANS 207:2011, 2011). The purpose of a geogrid is to prevent collapse, the ultimate limit state, and to retain serviceability. As a result, the reinforcement's existence satisfies the embankment structure's overall serviceability limit state criterion. To provide safety against collapse, partial material factors, and load factors are used, and when evaluating deformations or strains, different numerical values of load factors are used. When assessing the magnitude of settlements, all partial factors are set to a value of unity, except for those related to reinforcements (SANS 207:2011, 2011).

Limit state design emphasizes that the strength of the structure should be equal to or exceed the applied load. The stability of reinforced soil applications must consider both the ULS of collapse and the SLS in terms of external and internal stability. External stability involves evaluating the stability of the reinforced soil mass. Internal stability is determined by the interaction between the soil and the reinforcement, which occurs through friction or adhesion. The interaction also involves the transfer of load from soil to reinforcement based on the characteristics of the reinforcement. The design strength of the reinforcement may be governed by either the ULS of collapse or the SLS (SANS 207:2011, 2011).

3.2 Partial Safety Factors

For every material utilized in civil engineering, safety factors are incorporated during the design phase. To account for the material's long-term design strength—which is necessary when using a geosynthetic as reinforcement—safety factors are added to the tensile strength determined in the testing facility (ISO 10319 or ASTM D4595) (Zannoni, 2011). To determine the design strength the unfactored geogrid base strength is divided by material and economic partial factors. A summary of the partial factors used in the design of embankments according to SANS 207:2011 is shown in Figure 2.

1	2	3	4
Partial factors		**Ultimate limit state**	**Serviceability limit state**
Load factors	Soil unit mass, e.g. embankment fill	f_{fs} = 1,3	f_{fs} = 1,0
	External dead loads, e.g. line or point loads	f_f = 1,2	f_f = 1,0
	External live loads, e.g. traffic loading	f_q = 1,3	f_q = 1,0
Soil material factors	To be applied to tan φ'_{cv}	f_{ms} = 1,0	f_{ms} = 1,0
	To be applied to c'	f_{ms} = 1,6	f_{ms} = 1,0
	To be applied to c_u	f_{ms} = 1,0	f_{ms} = 1,0
Reinforcement material factor	To be applied to the reinforcement base strength	The value f_m should be consistent with the type of reinforcement to be used and the design life over which the reinforcement is required (see 8.3.3 and annex A)	
Soil/reinforcement interaction factors	Sliding across surface of reinforcement	f_s = 1,3	f_s = 1,0
	Pull-out resistance of reinforcement	f_p = 1,3	f_p = 1,0

Figure 2: Partial factors considered in the design of embankments according to SANS 207:2011

3.3 Design Methods for Reinforced Embankments on Soft and Very Soft Foundation Soils

The construction of embankments on soft soil foundations poses a significant challenge for geotechnical engineers. The inherent weakness of these foundations can lead to bearing capacity issues and compromise overall stability, particularly during the construction phase. This section explores two scenarios that apply geogrids, as shown in Figure 3, as a viable strategy to mitigate these concerns according to the SANS 207:2011.

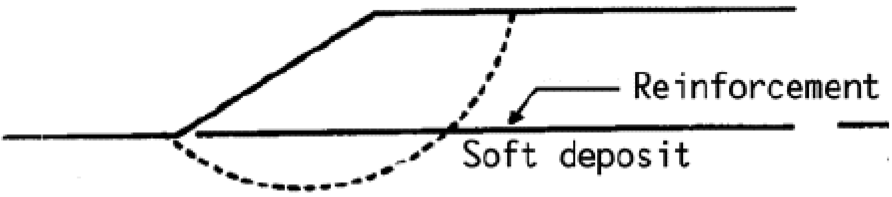

Figure 3: Embankment with geogrid reinforcement

3.3.1 Using High-Strength Geogrids to Control Embankment Stability

The shearing resistance of the foundation mostly determines the stability of an embankment built on soft soil, making it primarily a bearing capacity issue. Any decrease in differential settlement is secondary. Reinforcement can be erected at the foundation level to prevent shear failure in the foundation soil as well as the embankment fill. During construction, an embankment's stability on soft soil is especially important. This is due to the soft foundation's comparatively poor permeability, which prevents complete consolidation within the typical building timeline. Despite applying embankment stress at the end of construction, the foundation's shearing resistance improvement from consolidation might not be enough for stability.

Consolidation frequently eliminates the requirement for reinforcement to increase stability because it leads to an improvement in the foundation's shearing resistance (SANS 207:2011, 2011). The primary strength requirement of the reinforcement is that the factored reinforcement design strength equals or surpasses the design load at any given period between the completion of construction and the consolidation of the foundation. Shear forces from the foundation soil and fill transfer to the reinforcement, causing it to become tensioned and producing this stabilizing force. The following are the ultimate limit states that need to be considered: foundation extrusion stability; local stability of the embankment fill; rotational stability of the embankment; and lateral sliding stability of the embankment fill. The two serviceability limit states that need to be considered are excessive strain in the reinforcement; and foundation settlement (SANS 207:2011, 2011).

3.3.2 Using High-Strength Geogrids as a Component to Control Embankment Stability and Settlement

A variety of pile configurations, including driven or cast in-situ concrete piles, timber piles, grout-injected stone columns, sand compaction piles, and stone or concrete columns, can be employed below embankments. Normally, all embankment loading is expected to be transmitted via the piles and down to a solid stratum. As a result, the features of the soft foundation soil and the embankment's performance must only be considered when choosing and installing the right kind of piles (SANS 207:2011, 2011).

Transferring the embankment loading onto the piles may be accomplished by basal reinforcement that crosses the pile caps. Reducing the size of the pile caps and increasing the pile spacing are both made possible by the geogrids. The following are the ultimate limit states that need to be considered: pile group capacity; pile group extent; vertical load shedding onto the pile caps; lateral sliding stability of the embankment fill; and overall stability of the piled embankment. The two serviceability limit states that need to be considered are excessive strain in the reinforcing and piled foundation settling (SANS 207:2011, 2011).

4 Certifications and Accreditations of High-Strength Geogrids

The quality of geogrids needs to be ensured through rigorous testing and certification processes. Besides the mandatory certifications, there are voluntary certifications that highlight the product's behaviors. Independent organizations, separate from the supplier or the manufacturer can assess geogrids. The *Conformité Européenne* (CE) certification ensures that geosynthetic products meet the safety and performance standards declared by the manufacturer (Delmas and Ehrenberg, 2022). The *British Board of Agrément* (BBA) offers valuable insights into the performance of new geogrid products. The certification of geogrids outlines the technical specifications and installation methods. The assessment primarily involves technical investigations of the product following standards such as the BS 8006:2010 (SANS 207:2011 for South Africa) (Zannoni, 2011). Additionally, to measure the grids' impact on the environment, *Environmental Product Declaration* (EPD) certification is essential (Bovea et al., 2014).

4.1 CE Marking

The CE marking is a sign that a product meets the essential requirements for health, safety, and environmental protection outlined by the European Union (EU) directives and regulations. For geosynthetics used in construction projects, the relevant directive is the *Construction Products Regulation* (CPR) 305/2011 (Delmas and Ehrenberg, 2022). Choosing CE-marked geosynthetic products increases confidence in the quality and consistency of materials used, reducing risks and project delays.

Grids undergo a comprehensive certification process to demonstrate their adherence to quality standards. This process provides engineers with technical data to confidently use in various ground improvement projects (Delmas and Ehrenberg, 2022).

4.2 BBA Certification

The certification verifies that the geogrids adhere to relevant building codes, ensuring that their use complies with the established safety standards. A crucial aspect of the certification is independent verification of the geogrid's technical specifications to ensure the accuracy and reliability of the data used for design purposes. The certification establishes well-defined assessment criteria and conducts technical evaluations that are thorough, to evaluate the performance of the geogrid. Moreover, valuable design considerations and installation guidelines are provided for professionals working with the geogrid. Regular surveillance of production and formal three-year reviews are part of the certification process. This ensures consistent quality and allows for ongoing evaluation of the geogrid's performance over time (BBA Cert. 03/4065, 2010).

4.2.1 Design Considerations for High-Strength Geogrids According to BBA Certification

The primary objective of designing reinforced soil structures is to determine the required strength and stiffness of the geogrid reinforcement to maintain stability and limit deformations to acceptable pre-defined limits over the structure's design life. It is essential to consider the time-dependent reduction in strength or increased deformation that may occur in the geogrid due to factors like creep while determining the design life of the structure (Naughton and Balderson, 2005). A clear focus on site preparation, construction, material properties, drainage, product protection, and nearby structure stability is crucial. The certification assesses how the geogrid interacts with soil. This includes evaluating factors that are crucial for design purposes such as direct sliding and pull-out resistance to assist in finding the right grade of geogrid to use for a project. The design guidelines that follow adhere to the BBA certificate. The design strength (T_D) of the geogrid is calculated as:

$$T_D = \frac{T_{CR}}{f_m} \qquad \text{(Equation 1)}$$

where,

T_{CR} (Long-Term Creep Rupture Strength): This parameter refers to the grid's ability to withstand sustained tensile loads over its design life and at the expected operating temperature. The T_{CR} value essentially establishes the maximum long-term tensile load the geogrid can sustain without failure and can be found using the BBA certificate by dividing the characteristic short-term tensile strength of the reinforcement by the reduction factor of creep, RF_{CR}, found in the document:

$$T_{CR} = \frac{T_{char}}{RF_{CR}} \qquad \text{(Equation 2)}$$

$$f_m = RF_{ID} \times RF_W \times RF_{CH} \times f_s \qquad \text{(Equation 3)}$$

f_m (Material Safety Factor): The material safety factor accounts for various potential factors that may reduce the strength of the geogrid over time. These factors include:

- The Reduction Factor for Installation Damage, RF_{ID}: Improper installation techniques can damage the geogrid, potentially reducing its tensile strength.
- The Reduction Factor for Weathering, RF_W: Environmental factors like exposure to the sun can degrade the geogrid's material properties over time. A reduction factor of 1 may be applied for design purposes, given that the geogrids are shielded from direct sunlight exposure in alignment with the guidelines outlined in the certificate. Additionally, exposure periods should be restricted to a maximum of one month.
- The Reduction Factor for Chemical and Environmental Effects, RF_{CH}: The geogrid may encounter various chemical or environmental conditions during its design life that may affect the geogrid's tensile strength.
- While the reduction factors ensure a high degree of safety, they can also introduce some redundancy in coefficients. To address this potential redundancy and ensure a balance between safety and efficiency, a factor of safety, f_s, which can be found in the BBA certificate, is introduced to allow for the extrapolation of data.

When the high-strength geogrids are designed and installed according to the requirements of the BS 8006:2010 (SANS 207:2011 for South Africa), they are expected to have a life span of up to 120 years. This lifespan exceeds the typical design life required for ground improvement projects utilizing soil reinforcement (BBA Cert. 03/4065, 2010).

4.3 EPD Certification

The EPD certificate measures the impact that the geogrid has on the environment. To make it easier to compare the environmental impacts of similar items, the EPD provides quantitative environmental information about a product's life cycle. The study behind the current EPD adheres to the current Life Cycle Assessment (LCA) methodology, specifically tailored for the construction sector (Bovea et al., 2014). Product category rules, which specify the precise needs and directions for the construction of LCA research, are the basis for many different EPD programs worldwide. Consequently, environmental indicators for several influence categories across a product's life cycle are acquired and included in the EPD together with other environmental data (Bovea et al., 2014).

5 Conclusion

High-strength geogrids have emerged as a compelling solution for ground improvement in civil engineering applications. They address the limitations of unsuitable soil by enhancing soil properties through confinement, interlocking particles, and increased tensile strength. This paper examines the primary mechanisms through which high-strength geogrids improve soil properties, resulting in benefits such as enhanced structural stability, reduced settlements, improved load distribution, mitigation of lateral spreading, increased design flexibility for projects on challenging sites, and the potential for steepening slopes while reducing the foundation footprint. Careful design that considers factors like external loads, soil properties, geogrid characteristics, and external and internal stability is crucial.

Certifications ensure the quality and performance of geogrids. Certifications, such as CE marking and BBA certification, provide independent verification of technical specifications and adherence to safety standards. Additionally, EPD certifications measure the environmental impact of the geogrid, promoting sustainable construction practices. Overall, high-strength geogrids are a promising and valuable tool for achieving optimal performance in civil engineering projects. In conclusion, high-strength geogrids offer a reliable approach to ground improvement in civil engineering projects. The effectiveness, versatility, and cost-efficiency make these geogrids a valuable solution for engineering challenges to achieve optimal performance and stability in various construction projects.

References

BBA Cert. 03/4065 (2010) – Linear Composites soil reinforcement products – Paralink geocomposites – British Board of Agrement

Bovea, M.D., Ibáñez-Forés, V. and Agustí-Juan, I., 2014. Environmental product declaration (EPD) labeling of construction and building materials. In *Eco-efficient construction and building materials* (pp. 125-150). Woodhead Publishing.

Das, K., Chattaraj, S. and Bandyopadhyay, K., 2021, December. Review on the Application of Geosynthetic for Ground Improvement. In *Indian Geotechnical Conference* (pp. 79-89). Singapore: Springer Nature Singapore.

Delmas, P. and Ehrenberg, H., 2022, October. CE marking for geosynthetics. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1260, No. 1, p. 012039). IOP Publishing.

Jacob, B. and Naidoo, B., 2023. The use of high-strength geogrids in fill embankments. In *E3S Web of Conferences* (Vol. 368, p. 02024). EDP Sciences.

Koerner, R.M., 2012. *Designing with geosynthetics-Vol. 1* (Vol. 1). Xlibris Corporation.

Mulabdić, M., Minažek, K. and Kaluđer, J., 2018, May. Geogrids-what is important. In the *5th International Conference on Road and Rail Infrastructure (CETRA 2018)* (pp. 215-221).

Muthukkumaran, K., Rathod, D., Sujatha, E.R. and Muthukumar, M. eds., 2022. *Transportation and Environmental Geotechnics: Proceedings of the Indian Geotechnical Conference 2021 Volume 4* (Vol. 298). Springer Nature.

Naidoo, S. and Jacob, B., 2021. Geogrids in civil engineering applications. *IMIESA*, *46*(7), pp.24-25.

Naughton, P.J. and Balderson, T., 2005. The properties of polyethylene encased high tenacity polyester linear elements. In *Geosynthetics and Geosynthetic Engineered Structures, Contributions from the Symposium Honoring Robert M Koerner* (pp. 19-38).

SANS 207:2011, (2011). *The Design and Construction of Reinforced Soils and Fills*.

Zannoni, E., 2011. Criteria for the choice of geosynthetics in soil reinforcement: geosynthetics. *Civil Engineering=Siviele Ingenieurswese*, *2011*(1), pp.42-47.