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Geosynthetic-Reinforced Soil Systems for Different Landslide Stabilization

E. Bordbar, J. Jaramillo & T. Hasslacher
Huesker Synthetic GmbH, Gescher, Germany
bordbar@huesker.de
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Abstract

Landslides are among the most challenging geotechnical hazards affecting infrastructure and human safety, particularly in mountainous terrain and in areas with complex geological and hydrological conditions. In such environments, conventional stabilization methods may be difficult to apply because of high costs, limited access, and low tolerance to ground deformation. Geosynthetic-reinforced soil (GRS) systems provide a flexible and efficient alternative by combining the compressive and shear resistance of soil with the tensile capacity of geosynthetic reinforcement. This paper reviews the main mechanisms through which GRS systems contribute to landslide stabilization. Particular attention is given to soil-reinforcement interaction, confinement, global stability improvement, and drainage. These concepts are then linked to selected case histories involving reconstructed slopes, hybrid systems combined with piles or anchors, and protective embankments for active landslide zones. The reviewed applications show that the performance of GRS systems depends not only on reinforcement strength, but also on appropriate drainage, correct assessment of external and compound stability, and adaptation of the structural concept to site-specific conditions. The paper concludes that GRS systems represent a robust, deformation-tolerant and sustainable solution for landslide stabilization in a wide range of practical situations.

Keywords

Geosynthetics, Reinforced soil, Landslides, Slope stability, Geogrids.

1 Introduction

Landslides are among the most complex problems in geotechnical engineering because their development is controlled by the combined effects of geology, groundwater, terrain geometry, loading conditions, and construction activities. In mountainous regions, the resulting instabilities frequently threaten roads, railways, and other built infrastructure, often under severe constraints of access, construction time, and environmental sensitivity (Alexiew 2007; Plankel and Alexiew 2018). Conventional stabilization methods such as rigid retaining structures, deep foundations, or extensive ground replacement can be effective, but they are often difficult to implement in steep terrain because of high costs, construction constraints, and limited tolerance to ground deformation.

In contrast, geosynthetic-reinforced soil (GRS) systems offer a flexible and efficient alternative. These systems rely on the interaction between soil and geosynthetic reinforcement layers, which mobilize tensile resistance and enhance the overall mechanical behavior of the reinforced soil mass (Alexiew 2007). The resulting composite material can be used to construct steep slopes and retaining structures, to rebuild failed masses, or to create stabilizing toe buttresses. Compared with rigid systems, GRS structures can accommodate deformation more readily, which is particularly advantageous in slopes where some residual or progressive movement may continue after the stabilization works.

A further advantage of GRS systems is their practical adaptability. Many of the documented projects rely on the reuse of locally available soils, which reduces transport requirements and environmental impact. In addition, lightweight reinforcement products are easier to transport and install than conventional structural materials, which is important in remote mountain terrain or where construction time is very limited (Plankel and Alexiew 2018; Detert and Fantini 2014). At the same time, the field experience reported in the literature makes it clear that reinforcement alone is not sufficient. The success of these systems depends equally on adequate drainage, proper control of fill placement and compaction, and a stability concept that addresses internal, external, and compound failure modes.

Against this background, the aim of the present paper is to discuss the application of GRS systems in landslide stabilization from both a theoretical and a practical perspective. The paper first reviews the main stabilization mechanisms and then synthesizes selected case histories to show how these principles are translated into successful engineering solutions.

2 Mechanism of landslide stabilization using GRS

The stabilizing effect of GRS systems results from the interaction between soil and reinforcement and from the way the reinforced mass modifies the overall stress and deformation pattern within a slope. When a reinforced soil body is subjected to loading, relative displacement develops between the soil and the geosynthetic layers. This interaction mobilizes tensile forces in the reinforcement, which contribute additional resistance across potential failure surfaces. Since soil is weak in tension, the reinforcement provides the tensile component that the soil mass lacks, thereby increasing the overall resistance against sliding (Alexiew 2007).

From a simplified limit-equilibrium perspective, the stabilizing contribution of reinforcement may be expressed as an increase in the resisting forces acting along the critical failure mechanism:

$$F_s = \frac{R_s + R_r}{D} \tag{1}$$

Where F_s The factor of safety
R_s resisting contribution of the soil
R_r additional resistance provided by the reinforcement
D driving forces acting along the potential failure surface

In practice, design is carried out using established methods such as Bishop or Janbu analyses and by checking internal, external, and compound stability rather than by using this simplified expression

directly, but the equation illustrates the fundamental role of reinforcement in slope stabilization (Alexiew 2007; Arab et al. 2017).

GRS also improves confinement within the soil mass, reduces lateral deformation, and enables the reinforced zone to act as a coherent stabilizing body. In many landslides, however, reinforcement alone is insufficient if groundwater conditions remain unfavorable. For this reason, drainage is a central element of GRS stabilization systems. Drainage mats, trenches, pipes, blankets, and geo-composites are commonly used to reduce pore pressures and maintain drained conditions in and around the reinforced zone (Dalla Torre et al. 2006; Arab et al. 2017).

A further advantage of GRS systems is their ductile behavior, which allows them to accommodate deformation and makes them well suited to unstable terrain and progressive slope movement.

3 Case-Based Analysis of GRS Applications

The available case histories show that the same basic GRS principles can be adapted to very different landslide conditions. A representative early example is the Steinmaderer Wand project in Lech, Austria, where a failed slope below a ski-lift station was reconstructed using local soil, geogrid reinforcement, and drainage mats placed along the former failure interface. The structure was completed in less than two months and remained stable over decades, demonstrating the long-term effectiveness of combining reinforcement, drainage, and careful compaction in one integrated system (Alexiew 2007; Plankel and Alexiew 2018). A typical cross section of this structure is presented in Fig. 1.

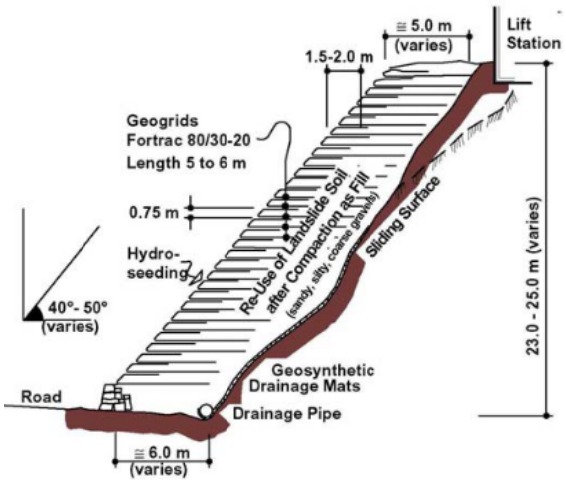


Fig. 1 Typical cross-section of a geogrid-reinforced slope constructed for landslide stabilization, including drainage layer at the former failure interface and wrapped-around facing (Alexiew, 2007).

A larger-scale application was reported for Lona-Lases near Trento, Italy, where instability related to quarry excavation and elevated pore pressures was mitigated by constructing a reinforced steep vegetated slope about 60 m high at the toe of the unstable mass (Fig. 2). The project included extensive drainage and monitoring, highlighting that in deep-seated landslides the reinforced structure functions not only as a retaining system but also as a stabilizing toe support that helps restore slope equilibrium (Dalla Torre et al. 2006).



Fig.2 Landslide stabilisation in Trento, Italy (Dalla Torre et al. 2006).

Further developments show that GRS systems can also be combined with structural elements where deeper instability or weak foundations govern the problem. In the Trieben-Sunk project in Austria, steep reinforced slopes were used together with drainage and anchorage measures in creeping alpine terrain, while other reported projects combined reinforced soil with piles or dowelling columns to improve external stability (Detert and Fantini 2014; Alexiew 2007) (Fig. 3). Protective reinforced embankments have also been used beside active landslide zones where direct removal of unstable material was impractical, showing that GRS can function both as a reconstruction method and as a protective stabilization measure (Russo et al. 2010).

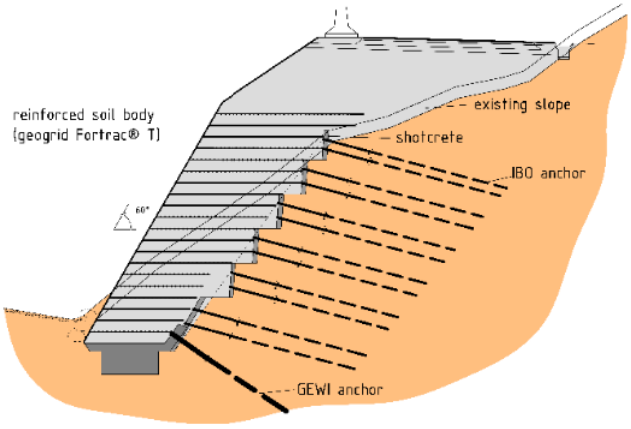


Fig. 3 Typical cross-section of a geogrid-reinforced slope constructed for landslide stabilization, including drainage layer at the former failure interface and wrapped-around facing (Detert O, Fantini P 2014).

In addition to slope stabilization, GRS systems have been successfully applied as protection structures against geohazards such as rockfall and avalanches. In these applications, reinforced soil structures function as flexible barriers capable of absorbing and dissipating impact energy through controlled deformation (Fig. 4). This behavior is enabled by the composite interaction between soil and geosynthetics, which provides both strength and ductility. Case studies demonstrate that such systems can withstand repeated dynamic loading while maintaining structural integrity, making them a reliable solution for protective infrastructure in mountainous terrain.



Fig.4 Geosynthetic-reinforced soil (GRS) for rockfall protection embankment at Zinödl, Austria (Huesker Synthetic).

4 Discussion

The reviewed projects confirm that the success of GRS systems in landslide stabilization. Special attention should be given to a hydro-mechanical design approach rather than on reinforcement strength alone. In nearly all cases, water management was a decisive factor. Whether the solution involves drainage mats at the old failure interface, sub-horizontal micro-drains within the slope, a mineral or geosynthetic drainage behind the reinforced body, or a drainage layer at the foundation level, the common goal is to reduce pore pressures and preserve the effective stress and thus the shear resistance conditions on which the stability of the reinforced mass depends. This repeated pattern in the case histories illustratesthat drainage should be treated as a primary design component from the start and not as a secondary detail.

Another clear observation is that flexibility is a major advantage of GRS systems when compared with conventional rigid retaining structures. Reinforced soil systems can deform while continuing to function, which is especially important in terrain where perfect arrest of all movement is unrealistic. This does not mean that they can compensate for deficient geotechnical investigation or inadequate external stability checks. On the contrary, some of the combined solutions reported in the literature show that deep-seated failures or weak foundations may require piles, dowelling columns, or anchorage in addition to the reinforced soil structure. The practical lesson is therefore that GRS works best when its deformation tolerance is used intelligently within a broader stability concept.

The case histories also demonstrate the constructive and environmental advantages of these systems. The frequent reuse of local soils, the reduced need for concrete and heavy structural materials, and the possibility of vegetated facings make GRS particularly attractive in mountain landscapes and on road projects where access is difficult. At the same time, it is worth to note that such advantages are only realized when fill quality, reinforcement layout, compaction, and long-term design strength are considered carefully. In other words, GRS is not simply a low-cost substitute for conventional stabilization, but a specialized engineered system whose performance depends on correct design and execution.

5 Conclusion

Geosynthetic-reinforced soil (GRS) systems provide an effective and versatile solution for landslide stabilization. Their contribution to stability is based on the interaction between soil and reinforcement, which mobilizes tensile resistance, improves confinement, and allows the reinforced mass to function as a coherent stabilizing body. Their performance depends on proper drainage, which is essential in slopes where increased pore pressure is the principal trigger of instability.

The reviewed case histories show that GRS systems can be adapted to a wide range of engineering situations, from rapid reconstruction of failed slopes, through large reinforced toe buttresses and steep slope stabilization, to hybrid systems combined with piles or anchors and protective embankments

built in front of active landslide zones. Their most important practical advantages are flexibility, deformation tolerance, constructability in difficult terrain, and the possibility of using local materials.

At the same time, the literature makes it clear that successful application requires more than simply selecting a reinforcement product. Reliable performance depends on an appropriate understanding of the failure mechanism, careful assessment of internal and external stability, and the integration of drainage into the structural concept. When these conditions are met, GRS systems represent a robust, economical, and sustainable approach to landslide stabilization.

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