"Advances in Geosynthetic Reinforced Soil Design"

by Dr. Jorge G. Zornberg, 2004 IGS Award Recipient

Editor's Note: Dr. Jorge G. Zornberg received a 2004 IGS Award at GeoAsia 2004 in Seoul, Korea, for his contributions to "Advances in Geosynthetic Reinforced Soil Design." The following article was contributed by Dr. Zornberg upon request.

Gone are the days when designs involving geosynthetic reinforcement struggled to demonstrate that these new systems are as reliable as and more cost effective than conventional structures. Instead, today's challenge is to demonstrate that geosynthetic reinforcement can be used to solve problems deemed unsolvable using conventional systems. These new challenges are being addressed through: (a) advances in design for conventional loads and geometries, (b) advances in design for unconventional loads and geometries, and (c) advances in reinforcement materials. This article comments on some of these advances, which were recognized by this IGS Award.

Advances in Design for Conventional Loads & Geometries

Geosynthetic-reinforced structures are conventionally designed using methods based on limit equilibrium. Current design guidelines for geosynthetic-reinforced soil structures disagree over the shear strength parameters that should be selected to characterize the backfill material. Most geosynthetic-reinforcing materials are classified as extensible inclusions for almost all practical applications. The extensible nature of geosynthetic reinforcements has often led to recommendations involving the use of the residual shear strength instead of the peak shear strength for design. However, common practice in the design of earth structures has been to use the peak shear strength. Accordingly, an experimental testing program involving reduced-scale models tested in a geotechnical centrifuge was conducted to evaluate this and other aspects in geosynthetic-reinforced soil design (Figure 1). The centrifuge results indicate that the stability of geosynthetic-reinforced slopes is governed by the peak soil shear strength (Zornberg 2002). There has been a significant debate on how such findings should be incorporated into design procedures. Yet, there is overall agreement that limit equilibrium approaches are suitable as the basis for design of reinforced soil structures (Zornberg et al. 1998, Zornberg and Arriaga 2003).

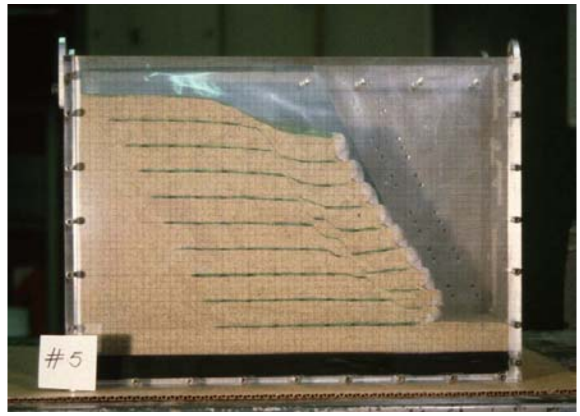

Figure 1. Geosynthetic-reinforced soil model brought to failure in a geotechnical centrifuge.

Advances in Design for Unconventional Loads & Geometries

Significant advances are taking place regarding the use of geosynthetic-reinforced soil structures to support unconventional loads. A good example is the use of reinforced soil systems as an integral component of bridge abutments and piers. Use of these systems to directly support both the bridge (e.g., using a shallow foundation) and the approaching roadway structure has the potential of significantly reducing construction costs, decreasing construction time, and smoothing the ride for vehicular traffic by eliminating the 'bump at the bridge' caused by differential settlements between bridge foundations and approaching roadway structures (Zornberg et al. 2001). The most prominent geosynthetic-reinforced soil abutment for bridge support in the US has recently opened to traffic near Denver, Colorado (Figure 2). The results from an extensive monitoring program of this structure indicate an excellent overall performance with negligible post-construction movements after an in-service period of one year (Abu-Hejleh et al. 2002). Geosynthetic-reinforced soil structures have also shown that they are particularly suitable in cases involving major differential settlements and seismic loads (Zornberg and Kavazanjian 2001). Of particular relevance, an evaluation of geosynthetics in seismic applications demonstrated that polymeric reinforcement maintains most of its original tensile strength after significant periods of sustained creep (Zornberg et al. 2004).

Geosynthetic reinforcements are particularly suitable in projects involving unconventional geometries. A good example is the use of geosynthetic reinforcements to stabilize steep veneer slopes such as cover systems for waste containment facilities. The use of uniaxial reinforcements placed along the slope and anchored at its crest has been a common design approach; however, there are other alternatives particularly suitable for steep veneer slopes. These include the use of uniaxial reinforcements placed horizontally (rather than along the slope) and anchored into the underlying mass, e.g., the reinforced cover system constructed as part of the final closure of the Operating Industries, Inc. (OII) Superfund landfill (Figure 3a). In this project, severe site constraints were overcome by constructing an alternative cover that incorporated horizontal geosynthetic veneer reinforcement (Zornberg et al. 2001). Figure 3b shows the typical veneer reinforcement detail. Approximately 500,000 m^3 of soil and 170,000 m^2 of geogrid were placed. The total area of geogrid placement exceeded 9.3 hectares, with reinforced landfill slopes up to 55 m in height. The different methods for stabilization of steep veneers using geosynthetics are summarized by Bouazza et al. (2002).

Advances in Reinforcement Materials

The development of new geosynthetic materials plays a significant role when confronting problems that cannot be addressed using conventional systems. A good example is the case of reinforcement of poorly draining backfills. Specifically, a promising approach for the design of reinforced marginal soils involves products that promote lateral drainage while providing soil reinforcement. This can be achieved using geocomposites with in-plane drainage capabilities. This design approach may even lead to the elimination of external drainage requirements (Zornberg and Mitchell 1994, Mitchell and Zornberg 1995).

A significant development regarding new reinforcement materials involves the use of fiber reinforcement. These reinforcement materials are particularly suitable for stabilization of thin soil veneers, where a small cohesion value has a significant impact on stability. Fiber reinforcement is also particularly adequate for projects involving the localized repair of failed slopes, where geometric constraints posed by the irregular shape of soil 'patches' are often difficult to solve using conventional continuous planar reinforcements.

Finally, the use of fiber reinforcement in seismically active areas can increase the yield acceleration used in design. A discrete approach for fiber-reinforced soil was recently developed in which fiber-reinforced soil is characterized as a two-component (soil and fibers) material (Zornberg 2002). This methodology can also be extended for inclusions involving recycled tire shreds (Zornberg et al. 2004). The proposed methodology treats the fibers as discrete elements that contribute to stability by mobilizing tensile stresses along the shear plane. Consequently, independent testing of soil specimens and of fiber specimens, but not of fiber-reinforced soil specimens, is used to characterize fiber-reinforced soil performance. Avoiding testing of fiber-reinforced soil specimens is a major achievement of the proposed approach since eliminating testing of composite specimens in design stages can encourage the implementation of fiber reinforcement in engineering practice.

In summary, while geosynthetic-reinforced soil structures are now well-established in conventional applications, their use in non-conventional projects continues to expand as a result of continued analytical, experimental, and field monitoring studies.

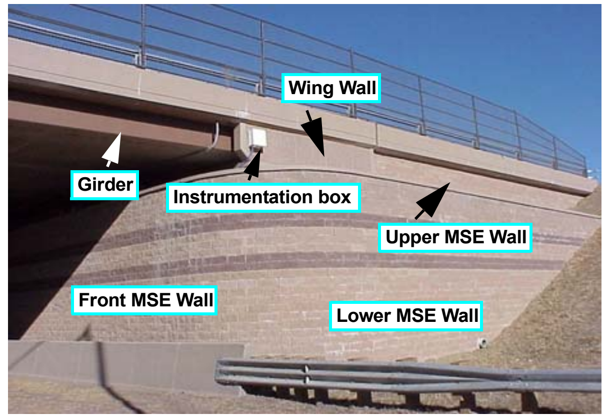

Figure 2. Founders/Meadows geosynthetic-reinforced bridge abutment.

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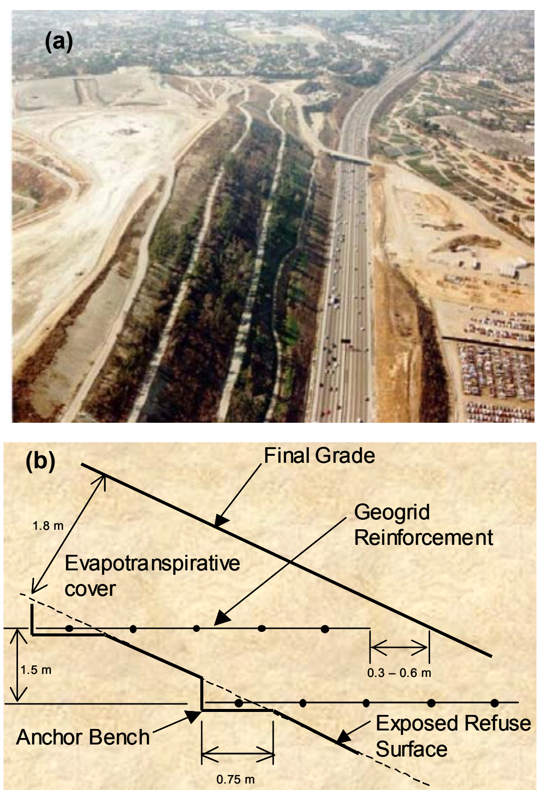

Figure 3. Reinforced cover at the OII Superfund Site: (a) view of steep cover slopes; (b) detail of cover reinforced using horizontal geogrids anchored in solid waste.