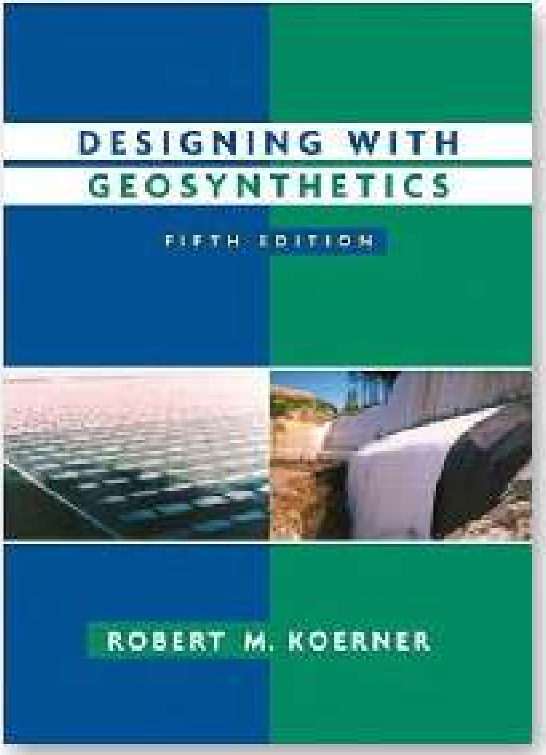
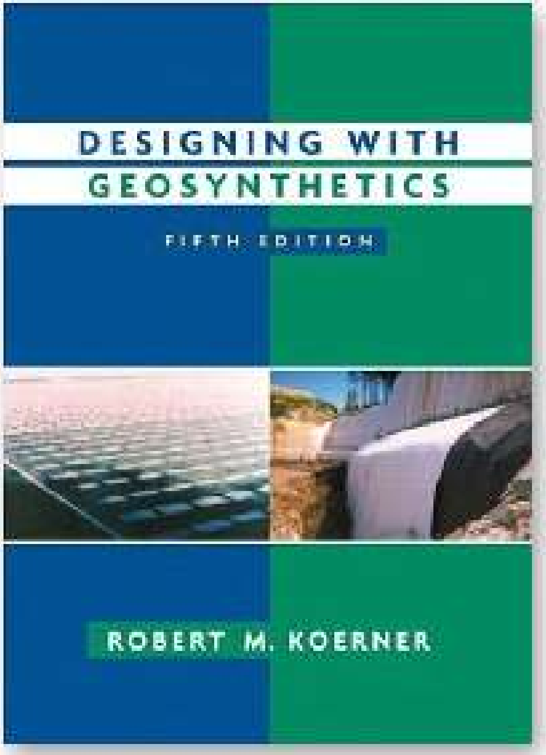


DESIGNING WITH GEOSYNTHETICS

FIFTH EDITION

ROBERT M. KOERNER



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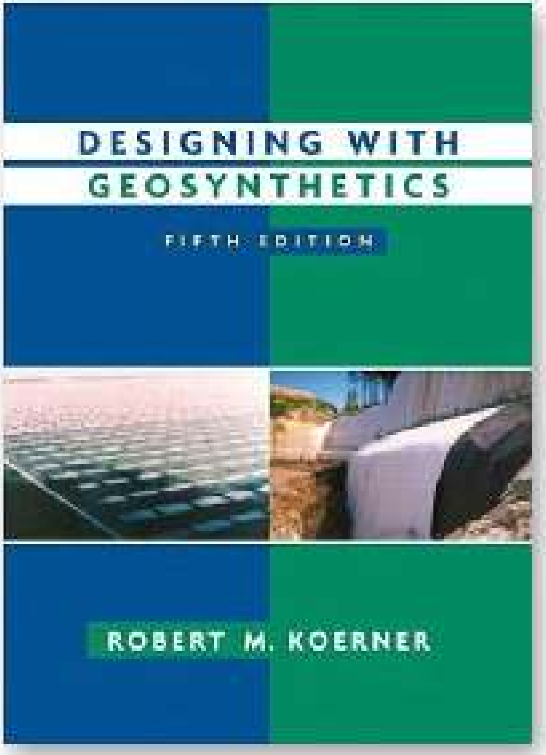

DESIGNING WITH GEOSYNTHETICS

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Continuous Fibers Leflaive [14] has pioneered the application of mixing continuous polyester threads with granular soil to steepen and/or stabilize embankments and slopes. The technique uses a specially designed machine capable of dispensing 23 m^3/hr of soil mixed with fibers coming from 40 bobbins, resulting in a weight percentage of 0.1 to 0.2%. The finished fiber-reinforced soil has fascinating properties. The system has been used in France where highway slopes of 60° have been constructed and have remained stable. Large field trials with enormous surcharges have failed to destroy the thread-reinforced soil mass. Laboratory studies on continuous fiber-reinforced granular soils have resulted in apparent cohesion values in excess of 100 kPa [15]. The use of the technique in the widening of highways or railroads that are in cut areas is quite attractive.

Three-Dimensional Geocells Rather than rely on friction, arching, and entanglements of fiber or mesh for improved soil performance, geosynthetics can be manufactured so that they physically confine the soil. Such confinement is known to vastly improve granular soil shear strength, as any triaxial shear test will substantiate. Furthermore, the increased shear strength due to confinement results in excellent bearing capacity.

The U.S. Army Corps of Engineers [16] in Vicksburg, Mississippi, has experimented with a number of confining systems, from short pieces of sand-filled plastic pipes standing on end to cubic confinement cells made from slotted aluminum sheets to prefabricated polymeric systems called sand grids or *geocells*. Geocells are typically made from HDPE strips 100 mm wide and approximately 1.2 mm thick. They are ultrasonically welded along their 100 mm width at approximately 300 mm intervals and are shipped to the job site in a collapsed configuration (see Figure 9.5). At the job site they are placed directly on the subsoil's surface and propped open in an accordian-like fashion with an external stretcher assembly. This section expands to a 5 by 10 m area of hundreds of individual cells, each approximately 250 mm in size. They are then filled with sand and compacted using a vibratory hand-operated plate compactor. The final step involves spraying the surface with an emulsified asphalt (approximately 60% asphalt in a 40% water suspension) at the rate of approximately 5 l/m^2. The water drains through the sand, leaving the asphalt globules in the upper portion of the sand, thereby forming a temporary wearing surface. In its expanded form, the system appears as shown in Figure 9.5. Tests have been conducted that have supported tandemaxle truck loads of 230 kN for 10,000 passes with only slight rutting. Without the system, the same trucks become bogged down in deep ruts after only 10 passes. There are a number of manufacturers that make different products within the geocell category. Most use high density polyethylene for the cell material, while a few use geotextiles for the cell materials. The various manufacturers should be consulted for their different material and geometric properties and for the latest styles that are available.

In terms of design, such systems are quite complex to assess. If we adapt the conventional plastic limit equilibrium mechanism as used in statically loaded shallow foundation bearing capacity (see Figure 9.6a), the failure mode is interrupted by the geocell system. For such a failure to occur, the sand in a particular cell must overcome the side friction, punch out of it, thereby loading the sand beneath the level of the mattress (see Figure 9.6b). This in turn fails in bearing capacity, but now with the positive effects of a small surcharge loading and typically higher-density conditions. The relevant equations are as follows, illustrated by Example 9.3:

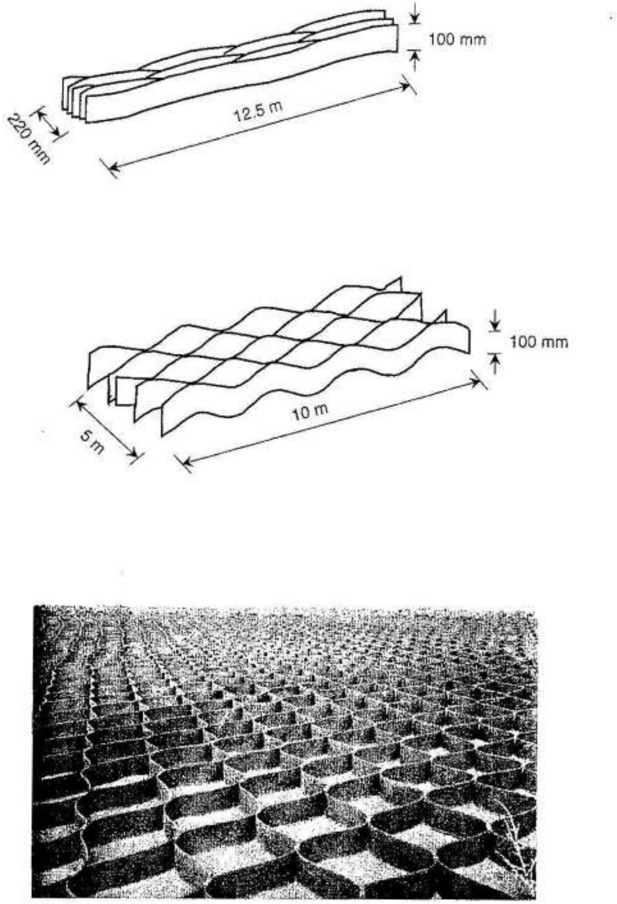
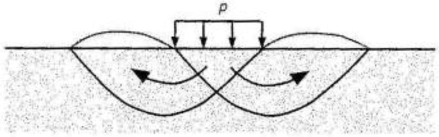


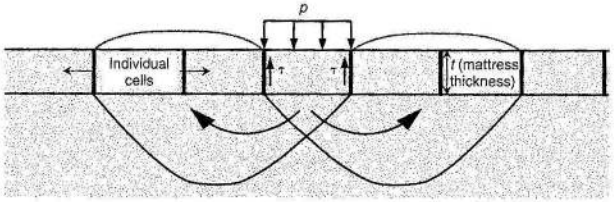
Figure 9.5 Diagrams and a photograph of a three-dimensional geocell for soil stabilization. (Compliments of Tenax Corp.)

Without mattress:

$$p = cN_c\zeta_c + qN_q\zeta_q + 0.5\gamma BN_\gamma\zeta_\gamma \tag{9.4}$$



(a) Without mattress



(b) With mattress

Figure 9.6 Bearing capacity failure mechanisms of sand without and with a geocell confinement system.

With mattress:

$$p = 2\tau + cN_c\zeta_c + qN_q\zeta_q + 0.5\gamma BN_\gamma\zeta_\gamma \tag{9.5}$$

where

p = maximum bearing capacity stress ($\cong$ tire inflation pressure of vehicles driving on the system if this is the application);

c = cohesion (equal to zero when considering granular soil such as sand);

q = surcharge load ($= \gamma_q D_q$), in which

γ_q = unit weight of soil within geocell, and

D_q = depth of geocell (recall Figure 9.6b);

B = width of applied pressure system;

γ = unit weight of soil in failure zone;

N_c, N_q, N_γ = bearing capacity factors, which are all functions of ϕ (where ϕ = the angle of shearing resistance [friction angle] of soil; see any geotechnical engineering text);

$\zeta_c, \zeta_q, \zeta_\gamma$ = shape factors used to account for differences from the plane strain assumption of the original theory (see geotechnical engineering texts) and

τ = shear strength between geocell wall and soil contained within it; note that $\tau = \sigma_h \tan\delta$ (for granular soils), in which

σ_h = average horizontal force within the geocell ($\cong pK_a$),

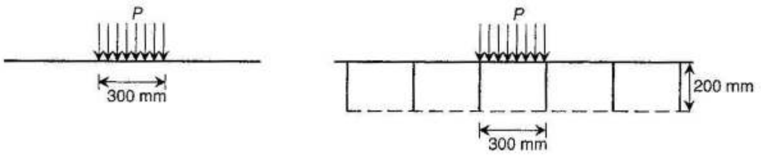
p = applied vertical pressure,

K_a = coefficient of active earth pressure. Note $K_a = \tan^2(45 - \phi/2)$, for Rankine theory, and

δ = angle of shearing resistance (friction angle) between soil and the cell wall material ($\cong$10 to 30° between sand and smooth or textural geomembranes, $\cong$20 to 30° between sand and geotextiles).

Example 9.3

Compare the ultimate bearing capacity of a sand soil **(a)** without and **(b)** with a geocell 200 mm thick and a friction angle of 18° to the geocell walls under the conditions shown below.



(a) Without geocell

γ = 15 kN/m³
ϕ = 20°
c = 0

(b) With geocell

γ = 16 kN/m³
ϕ = 27°
c = 0
σ_h = 20kPa (est.)
δ = 18°

Solution:

(a) Without a geocell

$$p = cN_c\zeta_c + qN_q\zeta_q + 0.5\gamma BN_\gamma\zeta_\gamma$$

Since $c = 0$ and $q = 0$;

$$\begin{aligned} p &= 0 + 0 + (0.5)(15)(0.30)(5.39)(0.60) \\ &= 7.3\ \text{kPa} \end{aligned}$$

(b) With a geocell, only $c = 0$.

$$\begin{aligned} p &= 2\tau + cN_c\zeta_c + qN_q\zeta_q + 0.5\gamma BN_\gamma\zeta_\gamma \\ &= 2(20)\tan 18° + 0 + (0.2)(16)(13.2)(1.51) \\ &\quad + 0.5(16)(0.30)(14.47)(0.60) \\ &= 13.0 + 0 + 63.8 + 20.8 \\ &= 97.6\ \text{kPa; which is 13 times greater than without the geocells} \end{aligned}$$

We can add the following to the description of geocells, the design method, and the various types of geocell products that are available:

- The bearing capacity improvement shown using geocells is very large.
- The use of thicker (i.e., greater depth) geocells will give proportionately greater improvement (see next topic).
- The use of a geotextile cell wall material with higher friction values than that used in the above analysis will give a proportionate improvement.
- With an increased densification of the soil infill, the improvement can be exponential.
- The dynamic effects of sand working under the mattress and gradually lifting it up out of position due to moving vehicles has not been considered. It is relevant, however, since it is a possible mode of failure.
- The solution given is for static bearing capacity; thus it is also suited for such problems as building foundations, embankment loads, earth dams, and retaining walls.
- Neither the foundation conditions nor the backfill types have to be cohesionless soils, as illustrated. Cohesive soils can be used in both situations and easily accounted for in the analysis.
- Geocell mattresses have been successfully used to construct *live* walls and for various slope stability situations by placing one section on top of the previous (with or without geosynthetic reinforcement). The analysis follows that presented in Chapters 2 and 3. Designs are also described by Richardson [17].

Three-Dimensional Mattresses. A deeper, more substantial mattress can be developed using a three-dimensional geosynthetic structure consisting, for example, of gravel-filled geogrid cells (recall Figure 3.21). These cells are typically 1.0 m deep and can be either square or triangular in plan view. They are joined together by a *bodkin* joint, an interlocking knuckle joint with a steel or plastic rod threaded through the intersection forming the coupling. Unitized polyolefin geogrids can be joined in this manner. Other geogrids must be joined by hog rings or other mechanical fasteners. The filling sequence is important, and John [18] suggests the following:

1. Fill the first two rows of cells to half height.
2. Fill the first row to full height.
3. Fill the third row to half height.
4. Fill the second row to full height.
5. Advance by repeating the sequence of half-height and full-height filling in Steps 1–4.

Edgar [19] reports on a three-dimensional geogrid mattress that somewhat parallels the geocells described above. The soil-filled geogrid mattress was constructed over soft fine-grained soils. A 32 m high embankment was successfully placed on top of it. It was felt that the nonreinforced slip plane was forced to pass vertically through the mattress and therefore deeper into the stiffer layers of the underlying subsoils. This improved the stability to the point where the mode of failure was probably changed from a circular arc to a less critical plastic failure of the soft clay. The application was considered to be a successful (and economical) one and parallels similar mattress support systems being used as foundations over soft soils for the support of landfills—for example, in Germany [20]. Many other applications, along with the related design methods are available, Richardson [17]

9.2.4 Reinforced Concrete Composites

Historically, fibers have been used to reinforce many different types of building materials. Some classic uses are straw in bricks, animal hair in plaster, and asbestos in cement. More recently, however, fiber-reinforced concrete has concentrated on steel, glass, and plastic fibers being placed in mortar, concrete, gunite, and shotcrete to improve their mechanical characteristics, particularly those of tensile, flexural, and impact strength [21]. The steel fibers are either round (made from wire) or rectangular (made from shearing sheets or from flattened wire) with lengths of 6 to 75 mm. Aspect ratios (length to thickness) range from 30 to 150. Smooth, crimped, and deformed fibers have also been used.

Typical glass fibers have diameters ranging from 0.005 to 0.15 mm but are usually bonded together to form diameters of 0.013 to 1.3 mm. Lengths are generally from 13 to 50 mm.

Typical plastic fibers that have been used are nylon, polypropylene, polyethylene, polyester, and rayon. Fiber diameters of 0.020 to 0.38 mm have been used; lengths of 13 to 50 mm are customary.

In general, the addition of fibers to cementatious materials results in the following improvements: greater resistance to cracking; holding cracked sections together; greater resistance to thermal changes, particularly shrinkage; thinner design sections; less maintenance, and longer life.

There is little standardization available regarding the amount of fibers to add to cementatious materials. The criterion is often dictated by how much fiber can be added before the mix becomes unworkable. This depends not only on volume, aspect ratio, type, and kind of fiber but also on the aggregate size, amount of sand, and amount of cement.

9.2.5 Reinforced Bitumen Composites

Including polymeric geogrids within bituminous pavement base courses with the idea of increasing the lateral modulus has been attempted. A number of the geogrids mentioned in Chapter 3 have been used. The attempts have only been of marginal success for two reasons: the softening (and sometimes the partial loss of prestress) of the polymers under the rather high temperature of the bituminous material as it is placed, and placement difficulties where the paving machine tends to pick up the geogrid and distort or tear it.