Design Method for Three-Dimensional Geocells on Slopes

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ABSTRACT: The aim of this paper is to provide the criteria for the selection of the suitable type of geocells for a given slope. The suggested design procedure allows to take into account the application of the geocells both on a soil slope and on a slope waterproofed with a smooth geomembrane. This latter case covers the use of geocells for capping of landfills and for other common applications. The design method considers the resistance of the junctions of the geocells and allows to determine the number of pegs or staples required to anchor the geocells to the ground without junctions failure. In case of use of the geocells on a smooth geomembrane, a geogrid is placed between geocells and geomembrane: the design method allows to determine the strength required for the geogrid. The design method presented in the paper is based on theoretical considerations, laboratory tests and field experience of the modes of failure.

1 INTRODUCTION

Geocells are geosynthetics which main function is soil confinement: they have the shape of a thick, honeycomb structure with robust walls and strong junctions. Geocells stabilize the soil or aggregate infilled by providing lateral confinement: in this situation the infiltration of the water is facilitated and the runoff is decreased both in volume and in speed, with consequent reduction of its erosivity. Rills and gullies are therefore prevented. In many cases the soil of a slope is rocky or totally arid, due to the lack of organic materials in the soil matrix. This situation often occurs when cutting a road slope, or in quarry areas or generally in rather dry regions. In this condition a minimum top soil layer of 70-100 mm is required to be laid on the arid soil for the vegetation to be successfully established on the slope. Top soil has low geotechnical characteristics and can easily slip down along slopes with an inclination greater than 30°, or it can be deeply eroded by heavy or sustained rains occurring prior to grass growth. Slopes with different length, inclination, soil characteristics, can be properly protected against erosion by the choice of the most suitable kind of geocells. In this application, geocells provide a structural function, since the stability of the top soil layer relies only on the geocell strength: hence all the possible failure mechanisms shall be properly evaluated, in order to define the minimum resistance required for the geocells.

Design methods for geocells have already been presented by Puig and Schaffner (1986) and by Wu and Austin (1992).

To the Authors' opinion, the two above design methods don't take into account all the possible failure mechanisms and all the possible applications.

The present paper, on the other hand, contains provisions for the different failure modes of the junctions, for the stability of the three blocks which the geocells can be divided into, for the installation of geocells on geomembranes, for the use of geogrid to increase the stability.

2 STABILITY ANALYSIS

The choice of the most suitable kind of geocells shall be based on stability analyses for the central block, the top block and the toe block. An additional analysis shall be performed in the case that the topsoil layer is much thicker than the geocells.

2.1 Stability analysis along the slope

The first stability analysis is performed for the central block. Reference is always made to Fig. 1a.

The weight W of the central block CDEF of the cellular confinement system filled of soil is:

$$W = \gamma L t \quad (1)$$

with: γ = unit weight of infill soil, [kN/m³];
L= slope length, [m];
t= depth of geocell, [m].

Hence the sliding force F is

$$F = W \ \text{sen}\beta \quad (2)$$

with: β = slope angle, [deg].

The global resisting force R_{tot} is calculated as the sum of all the single resisting forces:

$$R_{tot} = S + \frac{R_{crest}}{FS_j} + \frac{R_p}{FS_j} + R_g + P_p \quad (3)$$

where:

$$S = \gamma L T \cos\beta \tan\phi_i \quad (4)$$

is the frictional resistance along the slope,

with: ϕ_i = friction angle of the interface infill soil-subsoil (fig. 1a), or of the interface geocell-geogrid-geomembrane (fig. 1b), [deg].

At the top of the slope:

$$R_{crest} = n_j \ J_{min} \quad (5)$$

is the resistance at the crest provided by the sum of all the strength of the junctions,

with: n_j = n. of junctions per unit width of the geocells, [m^{-1}];
J_{min} = minimum junction strength, [kN/junction].
FS_j = factor of safety against junction failure.

FS_j takes into account the possible construction damages and the long term effect of the soil and the pins on the junction strength.

FS_j should have a minimum value of 1.5.

The junction strength J_{min} must be evaluated by means of specific laboratory tests. Typical tests are:

- junction shear: one strip is displaced relatively to the adjacent strip along the direction of the strips themselves;
- junction peeling: one strip is displaced relative to the adjacent strip, perpendicular to the direction of the strips themselves;
- junction splitting: two of the four convergent strips in the junction are stretched relative to the other two, perpendicular to the junctions.

A full description of the junction tests for geocells can be found in Montanelli and Rimoldi (1994).

Moreover:

$$R_p = b \ J_p \quad (6)$$

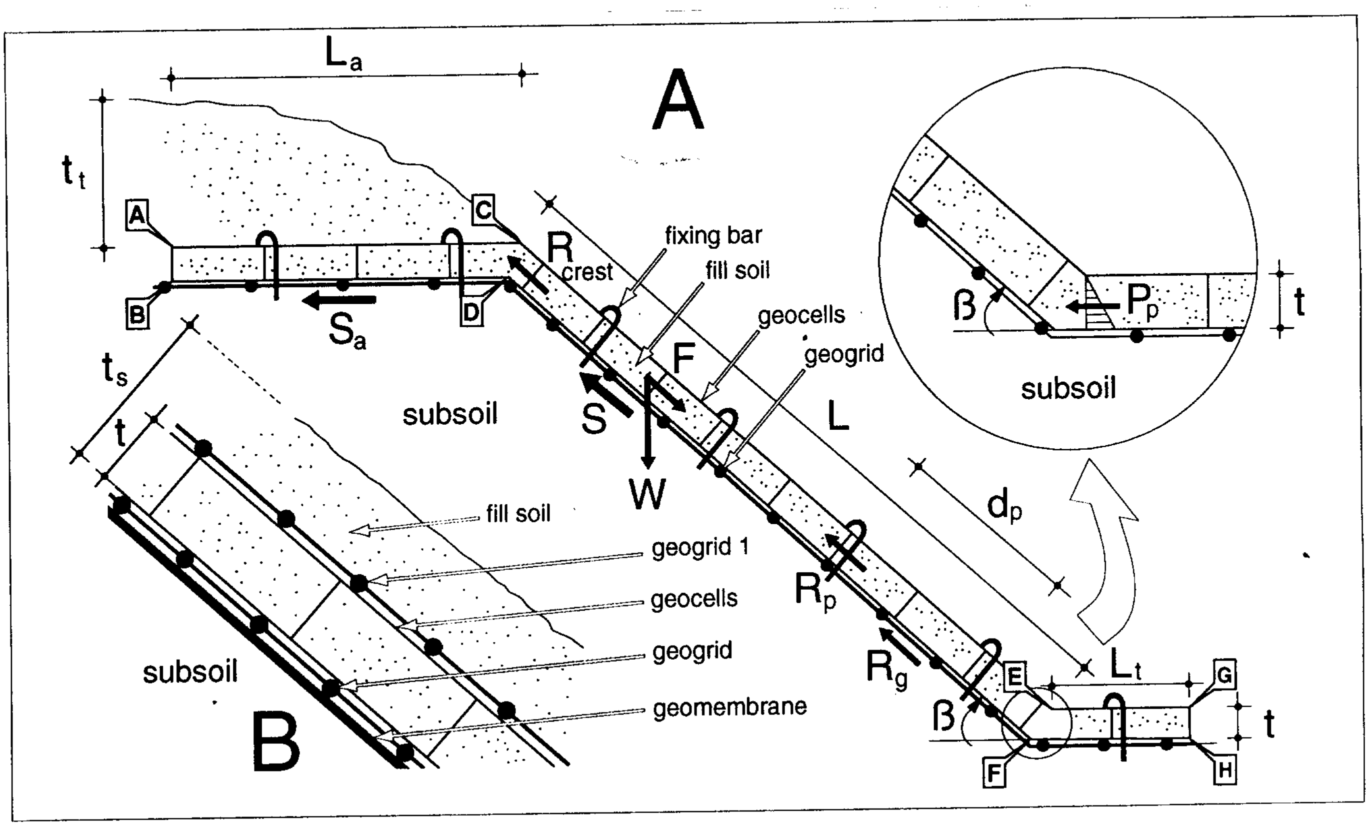

Fig. 1 - Scheme of the design problem: a) geocells on soil; b) geocells on geomembrane

is the additional resisting force provided by transferring the load through the fixing pins,

where: b = number of pins per unit width of the slope, distributed along the slope length L, $[m^{-1}]$;

J_p = shear strength of geocell junctions under the stress applied by pins [kN/junction].

Also J_p, like J_{min}, shall be evaluated by means of specific laboratory tests, a description of which can be found in Montanelli and Rimoldi (1994).

The spacing d_p, [m], of the pins/stakes along the slope is given by:

$$d_p = L \;/\; b \tag{7}$$

Pins/stakes shall be placed staggered, at the closer multiple of the geocells diameter which is smaller than d_p.

For the geogrid:

$$R_g = \alpha_{2\%} \tag{8}$$

with: $\alpha_{2\%}$ = tensile strength of the geogrid at 2% strain (only if a geogrid is placed under the geocells).

The use of the geogrid is required when the slope is steep or when there is a geomembrane under the geocells, with the consequent reduction of the friction angle at the interface.

The tensile strength at 2% strain is selected as the design parameter for the geogrid because, based on field observations, it is fundamental for stability that absolutely minimal displacements shall occur at the interface.

Finally:

$$P_p = 1/2 \; K_p \gamma \; t^2 = 1/2 \, \gamma \tan^2 (45° + \phi/2) \, t^2 \tag{9}$$

is the passive strength provided by adjacent cells at the toe of slope,

with: ϕ = friction angle of the infill soil, [deg].

The global factor of safety, FS_g, shall be calculated as the ratio between the resisting forces and the sliding force:

$$FS_g = R_{tot} \;/\; F \tag{10}$$

It should have a minimum value of 1.5.

2.2 Stability analysis of the anchorage block at the crest

The stability analysis along the slope allows the selection of the suitable product and the calculation of the spacing between pins while the stability analysis of the anchorage block ABCD (fig. 1a) allows to determine the breadth of the trench by setting its depth or viceversa. In fact the geocells need to be anchored to avoid their pull out from the trench. Note that, even if in the analysis of the central block we have considered R_{crest} as provided only by the junction strength, here we have to consider a higher active force because the single strips of the geocells may be locally loaded in excess of R_j. This fact was recorded in various field observations.

The factor of safety for the anchorage block shall be:

$$FS_a = \frac{S_a}{(F - S)\cos\beta} \tag{11}$$

where S_a is the horizontal component of the resisting force provided by the trench:

$$S_a = \gamma \, t_t \; L_a \; \tan\phi_{ia} \tag{12}$$

with: L_a = anchorage length, [m];

t_t = trench depth, [m];

ϕ_{ia} = friction angle at the interface fill soil - subsoil at the crest, [deg].

At the denominator the sliding force is decreased of the frictional resistance.

From eq. (11) and (12), when setting t_t based on the geometry of the project, we can calculate

$$L_a = \frac{FS_a \,(F - S)\cos\beta}{\gamma \, t_t \tan\phi_{ia}} \tag{13}$$

where FS_a is usually not less than 1.5.

Anyway L_a should have a minimum value of 0.75 m.

2.3 Stability analysis at the toe

The factor of safety for the stability of the toe block EFGH (see Fig. 1a) is provided by:

$$FS_t = S_t \;/\; P_p \tag{14}$$

where:

$$S_t = \gamma \, t \, L_t \tan\phi_i \tag{15}$$

with: L_t = anchorage length at the toe [m].

Hence L_t can be calculated as:

$$L_t = \frac{FS_t P_p}{\gamma t \tan\phi_i} \quad (16)$$

FS_t shall have a minimum value of 1.5.
L_t should be 1.0 m minimum.
Otherwise the geocells can be butted against a rigid support like a small wall or heavy concrete blocks.

2.4 Stability analysis for the topsoil

Sometimes the thickness of the soil is greater than the cells thickness. In this case we have to verify the stability of the soil at the interface with the superior face of the geocells (see fig. 1b), that is along the surface C-E in fig. 1a.
The sliding force in this case is:

$$F_1 = \gamma L (t_s - t) \quad (17)$$

with: t_s = total thickness of the soil, [m].
The total resistant force is given by:

$$R_{tot1} = S_1 + P_{p1} + R_{g1} \quad (18)$$

where the frictional resistance is:

$$S_1 = \gamma (t_s - t) L \cos\beta \tan\phi \quad (19)$$

The resistance provided by the toe block is:

$$P_{p1} = 1/2 \ \tan^2 (45° + \phi/2)\ (t_s - t)^2 \quad (20)$$

The resistance of the eventual geogrid placed on top of the geocells (geogrid 1 in Fig. 1b) is:

$$R_{g1} = (\alpha_{2\%})_1 \quad (21)$$

with: $(\alpha_{2\%})_1$= tensile strength of geogrid 1 at 2% strain.
The factor of safety is given by:

$$FS_1 = R_{tot1} / F_1 \quad (22)$$

and it shall have a minimum value of 1.3.

3 DESIGN PROCEDURE

Based on the equations above, the design procedure for geocells on slope is as follows:

1) Measure or estimate the soil characteristics and the friction angle at the interface.
2) Determine the sliding force F by means of eq. (2).
3) Select the type of geocells, set the required factor of safety for junctions FS_j, and set the number of pins b. Don't include any geogrid at this stage (hence put $R_g = 0$ for the moment).
4) Calculate the global resisting force R_{tot} by means of equations (3) through (9).
5) Determine the global factor of safety FS_g by means of eq. (10).
6) If FS_g is less than the value of 1.5, then increase the number of pins or insert a geogrid under the geocells. Define both b and $\alpha_{2\%}$ by a trial-and-error procedure, until the required FS is reached.

A fast procedure is to set the number of pins b through eq. (7) by putting d_p equal to 2-3 cells diameters; then the required tensile strength of the geogrid at 2% strain can be easily calculated as:

$$\alpha_{2\%} = FS_g F - \left(S + \frac{R_{crest}}{FS_j} + \frac{R_p}{FS_j} + P_p\right) \quad (23)$$

where FSg is set at the required minimum value.

7) Determine L_a by means of eq. (13), with eq. (2) and eq. (4).
8) Calculate L_t by means of eq. (16), with eq. (9).
9) In the case that the thickness of fill soil is more than the depth of the geocells, then calculate FS_1 with equations (17) through (22), putting initially $R_{g1} = 0$.
10) If FS_1 is less than the required value, then calculate the required tensile strength at 2% strain of geogrid 1 as:

$$(\alpha_{2\%})_1 = FS_1 F_1 - (S_1 + P_{p1}) \quad (24)$$

where FS_1 is set at the required minimum value.

4 REFERENCES

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