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A proven technology for strengthening slopes prone to erosion, suffusion and wind impact

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ABSTRACT

As part of the research used to protect slopes from erosion with traditional three-dimensional geocells, our engineers found 2 core problems: a) cell aggregate instability at inclined angles steeper than 45 degrees and b) aggregate being washed out from the cells when exposed to water flow. On the search for a solution to these problems, we have developed a new approach of geocell solution based on a slope collapse case in Russia. The new concept of geocell which is weld-free polymer three-dimensional cell is introduced as weld-free geocell made of polymer tape with transverse cuts and delivered in the form of rolls in order to facilitate transportation, storage and installation. Weld-free geocell is actively being introduced into hydrotechnical, road and civil construction all over the world. The result of the successful experience of using weld-free geocell can serve such objects: slope strengthening in an industrial park in Vietnam, slope reconstruction in Moscow, etc. As a result of the active implementation of weld-free geocell, technical and economic advantages were revealed in comparison with traditional three-dimensional geocells, reno mattresses, hydroseeding, and geomats. The main advantages of weld-free geocell are: high soil fixation on a slope due to the cell walls being perpendicular to the horizon, improved drainage properties, reduced cost per square meter up to 50% compared to other materials, accelerated installation process. Also, full-scale tests of weld-free geocell were carried out, including in accordance with ASTM D 6459-15, the results of which have developed methods for selecting weld-free geocell parameters for protecting slopes and for calculating structures.

Key words: geosynthetics, geocellular confinement systems, geocells, weld-free geocell, GEOSTEP, slope protection, hydraulic engineering construction, road construction.

1.INTRODUCTION

Protection of the surface of the slopes is a common problem in the construction of most objects of road, hydraulic, railway construction. The slopes are subjected to constant destructive influences, so all the slopes are eroded by precipitation, the dam slopes are affected by the flow of water and waves, ice, railway embankments slopes constant dynamic loads. Under the influence of such a number of loads, the slopes quickly collapse and the body of the embankment (structure) itself begins to deform, and these processes occur very quickly. Due to these numerous difficulties, a constructive solution for the protection of slopes should be technologically advanced, durable, simple and inexpensive during installation and operation. In our opinion, such a solution is constructions using three-dimensional geocells. However, when protecting the slopes from erosion using three-dimensional geocells, there is often a problem of washing out the aggregate material from the cells when exposed to water flow. This is due to the location of the cell walls at an angle to the horizon. As a result, after each heavy rain, the filler is washed out of the cells accumulates at the base of the slope, and voids are formed in the cells, so a complex of corrective works must be carried out annually. This deficiency was eliminated due to appliance of the new three-dimensional weld-free geocell (Figure 1) aimed for strengthening slopes. The walls of the weld-free geocell cells are perpendicular to the horizon; therefore, the filler material is not subject to sedimentation from the cells and, therefore, does not require annual correction work.

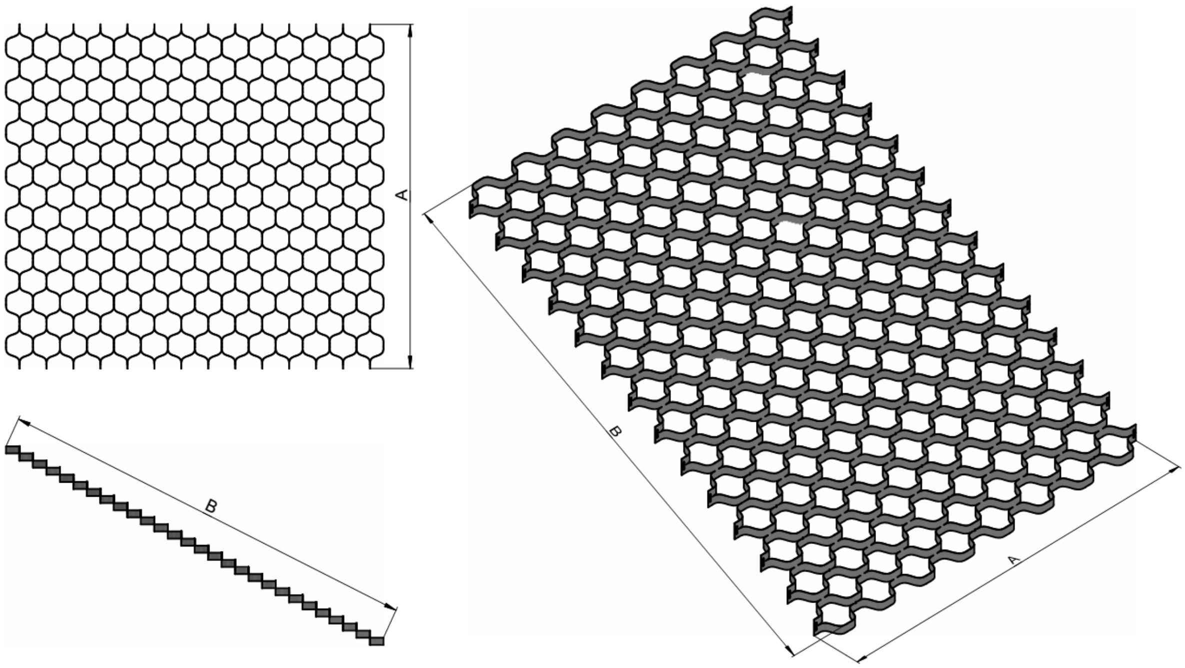

Figure 1. General view of a weld-free geocell.

Weld-free geocell (Figure 2) is an innovative material for reinforcing slopes, which is a polymer sheet with special longitudinal cuts arranged in a checkerboard pattern, it is produced according to STO 17996082-005-2015. For the convenience of the user, weld-free geocell is delivered in rolls. Under tension, a voluminous cellular structure is formed, intended to be filled with vegetative soil or rubble. Tables 1 and 2 show the main weld-free geocell sizes and basic physical and mechanical characteristics. These parameters are used in calculations of structures with geocells. We will talk about them later.

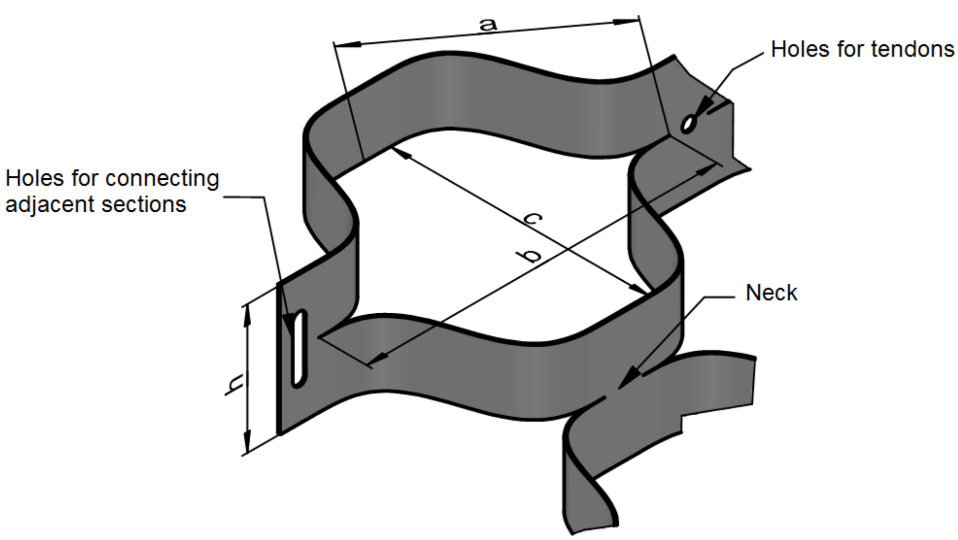

Figure 2. General view of weld-free geocell cells.

Table 1. Weld-free geocell cell size requirements (±10%).

PROPERTIES	VALUE					
Cell wall height, mm	75, 100, 150					
Cuts distance cuts, mm	330	356	400	445	660	712
Cell diagonal size, mm	225*207	255*211	292*274	320*300	426*416	512*486

Table 2. Weld-free geocell physical properties.

PROPERTIES	TYPE A	TYPE C	TYPE E
Material	HDPE		
Cell wall height, mm, ±10%	75, 100, 150		
Perforation,%, not more than	15		
Peak load under tension, non-perforated (Fpm), kN/m, not less	14	18	22
Peak load under tension - perforated, kN/m	0,6 Fpm		
Elongation / unit length at maximum load, non-perforated, %, not more	35		
Neck peak load, kN/m, not less	10	18	25

Typical construction of reinforcement of non-flood slopes (Figure 3) is, in general, identical to the reinforcement of slopes using three-dimensional geocells. Weld-free geocell is usually laid on the separation layer of non-woven geotextile, fixed to the surface of the slope with the help of anchors and filled with vegetative soil, followed by sowing of perennial grasses.

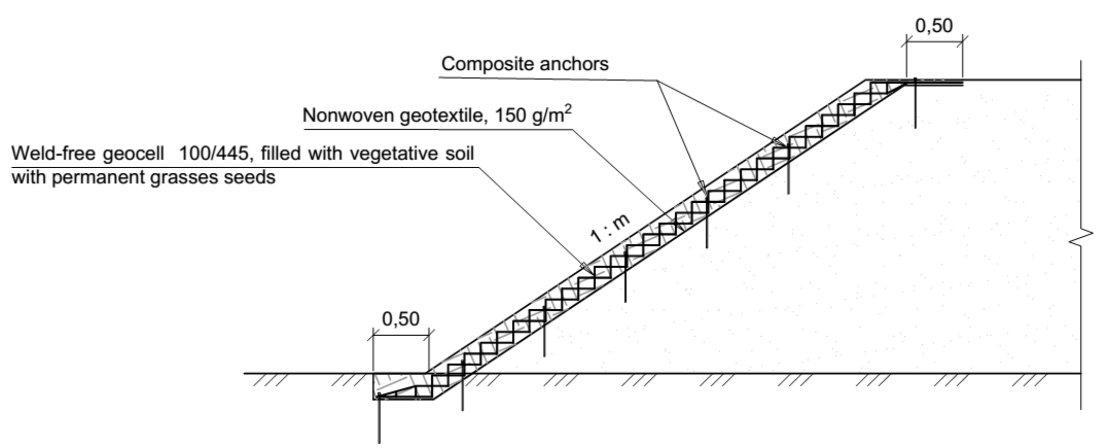

Figure 3. Design of strengthening non-flooded slopes.

Typical construction of reinforcement of flooded slopes is, in general, identical to the reinforcement of slopes using three-dimensional geocells. Weld-free geocell is placed on the separation layer of non-woven geotextile, fixed to the surface of the slope with the help of anchors. The selection of the weld-free geocell parameters is also carried out in accordance with the special materials. The aggregate material for the geocell is selected in accordance with the Table 3 depending on the speed of water flow along the slopes and the height of the wave.

Table 3. Conditions of use of the flooded structures strengthening slopes according to ODM 218.3.032-2013.

DESIGN STRENGTHEN WHEN FILLING CELLS	PERMISSIBLE WATER FLOW RATE V, M2/SEC	MINIMUM HEIGHT WAVES HB, M
Vegetative soil with hydroseeding grass	0,5	0,2
Reinforced soil	1,1	0,4
Crushed stone: 40-70 mm	1,0	0,3
Additional reinforcement with cement mortar	1,5	0,7
Concrete mix layer with a thickness of 7.5 cm at the top and the gravel layer with a thickness of 7.5 cm at the bottom	1,9	0,85
Concrete mix layer	2,3	1,2

At the same time, we do not recommend abandoning the use of traditional three-dimensional geocells in complex structures, such as strengthening the cones of bridges and overpasses, strengthening the surfaces of complex slopes and strengthening the slopes of increased steepness (retaining walls).
In the construction with three-dimensional geocells, the following materials are also used. Nonwoven geotextile is used to create a separation layer in difficult soil and geological conditions. According to our practice, this is almost 80% of cases. According to PNST 218-2018 for slope protection we need geotextile with these parametres: Recommendations on geotextiles: filtration coefficient should be not less than 10 m/day; tensile strength when using crushed stone as aggregate should be not less than 12 kN/m; tensile strength when using vegetative soil as a filler should be not less than 4 kN/m.

Anchors (Figure 4) are designed to fix weld-free geocell to the surface of the slope. Fastening is carried out in accordance with the following scheme: at the top and bottom of the module, anchors are placed in each cell; on the edges of the module, the anchors are placed through a single cell; on the module area, the anchors are staggered in 1.0-1.2m. We recommend using our composite anchors, since unlike traditional metal fittings, they do not corrode, which has a positive effect on the durability of the structure.

Figure 4. Anchoring system.

Fastening of the adjacent weld-free geocell sections can be made by using two methods: the traditional method with metal galvanized clips installed every 25mm and alternatively with fastening keys (Figure 5). The second method is more technological, since the auxiliary equipment in the form of a pneumatic stapler and compressor, as well as trained personnel are not required. In addition, the locking system is more durable, which has a positive effect on the durability of the structure.

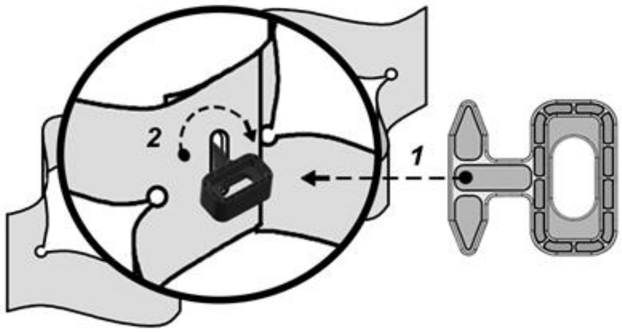

Figure 5. Fastening key.

For a more uniform distribution of the load on the cells while strengthening the high slopes, it is possible to use a polymer cable (Figure 6) as an additional measure to improve reliability. We recommend to use two types of cables: a diameter of 8mm with a breaking load of 750 kg/cm and a diameter of 10mm with a breaking load of 1000 kg/cm.

Figure 6. Polymer cable.

The basic principle calculating slopes reinforced with geocells: is that the safety factor (Eq.1), equal to the ratio of holding and shear forces, must be at least 1,25.

$$k = \frac{\sum T_r}{\sum T_w} \geq 1{,}25 \qquad [1]$$

ΣTr – sum of the forces holding the structure of the strengthening on the slope,
ΣTw – shear force from the weight of the reinforcement structure.
The shear forces (Eq.2) are the sliding force on the surface of the slope. It depends on the parameters of the geocell, the parameters of the aggregate material and the angle of the slopes.

$$\sum T_w = N \cdot n_c \cdot c \cdot b \cdot h' \cdot \gamma_{inf} \cdot \sin\beta \qquad [2]$$

Where:
N – numbers of modules geocell on the length of the slope (for weld-free geocell always 1),
n_c – numbers of cells on the length of the slope,
c, b – diagonal dimensions of the cell,
h' – height of the filler, taking into account its excess thickness (3-5 cm) above the geocell,
γ_{inf} – volumetric weight of filler material,
Sinβ – the sine of angle of laying the slope.
The holding forces (Eq.3) consist of the friction force on the surface of the slope, the holding forces from the anchors, the holding forces from the geocell resting against the bottom of the slope, and the holding forces from the cables (if any).

$$\sum T_r = T_{fr} + T_a + T_{sup} + T_{cord}$$ *[3]*

Where:
T_{fr} – Friction force,
T_a – Holding force from anchors,
T_{sup} – Holding force from stop,
T_{cord} - Holding force from cords.
The friction force (Eq.4), as well as the shear forces, depends on the parameters of the geocell, the parameters of the aggregate material and the angle of the slopes.

$$T_{fr} = N \cdot n_c \cdot c \cdot b \cdot \left(h' \cdot \gamma_{\inf} \cdot \cos\beta \cdot tg\phi'' + C'' \right)$$ *[4]*

Where:
N – numbers of modules geocell on the length of the slope (for weld-free geocell always 1),
n_c – numbers of cells on the length of the slope,
c, b – diagonal dimensions of the cell,
h' – height of the filler, taking into account its excess thickness (3-5 cm) above the geocell,
γ_{inf} – volumetric weight of filler material,
cosβ – the sine of angle of laying the slope,
tgφ", C" – values of internal friction angle and adhesion of soil (filler material).

When calculating the friction force, the smallest soil indicators are used: that is, if the adhesion and the angle of internal friction of the aggregate are less than the adhesion and the angle of internal friction of the soil of the subgrade, then the indicators of the aggregate are used in the calculation. If the clutch and the angle of internal friction of the aggregate are higher than the clutch and the angle of internal friction of the soil of the subgrade, then the indicators of the subgrade soil are used in the calculation. When using a separating layer of non-woven geotextile, additional reduction coefficients are introduced (0.6 to the tangent of the angle of internal friction and 0.1 to the adhesion of the soil).

$$\begin{aligned}
& tg\phi'' = tg\phi', C'' = C' \\
& if \\
& tg\phi_{\inf} \le tg\phi_m \rightarrow tg\phi' = tg\phi_{\inf} \\
& tg\phi_{\inf} \ge tg\phi_m \rightarrow tg\phi' = tg\phi_m \\
& C_{\inf} \le C_m \rightarrow C' = C_{\inf} \\
& C_{\inf} \ge C_m \rightarrow C' = C_m
\end{aligned}$$

When we use geotextile $tg\phi'' = 0.6 \cdot tg\phi', C'' = 0.1 \cdot C'$

The holding force from the anchors (Eq.5) depends on the parameters of the geocell and the number of anchors installed over the module area. In the formula, k is the coefficient taking into account the decrease in the characteristics of the geocell in time.

$$T_{anc} = N \cdot n_{anc} \cdot \frac{h \cdot R}{k_w}$$ *[5]*

Where
N – numbers of modules geocell on the length of the slope (for weld-free geocell always 1),
n_{anc} – numbers of cells with anchor,
h – cell height,
R – strength of weld,
k_w – geocell stability factor (k_w = 4).

The holding forces of the cables (Eq.6) depend on the strength of the cables and on the number of cables stretched through the section.

$$T_{anc} = N \cdot n_c \cdot \frac{R}{k_w} \quad [6]$$

Where:
N – numbers of modules geocell on the length of the slope (for weld-free geocell always 1),
n_c – numbers of cords per section,
R – strength of cord,
k_w – cord stability factor (k_w = 2).

Advantages of weld-free geocell comparing to other materials for reinforcing slopes:
1) traditional three-dimensional geocells: a) more affordable by 20–30% and b) aggregate does not pour out of the cells, which reduces the cost of operating the structure;
2) biomats / coconates: a) reinforces the surface of the slope, not letting it collapse before grass germination and b) can be used to strengthen flooded slopes and filled with rubble;
3) geomats / anti-erosion geogrids: a) possesses significantly higher breaking loads and b) can be used to strengthen flooded slopes and filled with rubble.

A comparison of the cost of strengthening 1 square meter of slope shows that weld-free geocell is the most cost-effective means for strengthening slopes (Figure 7).

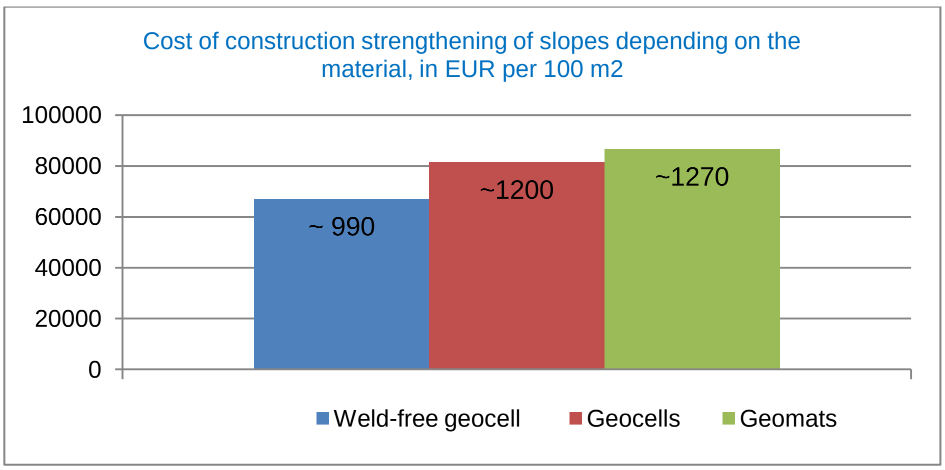

Figure 7. Cost of construction strengthening of slopes depending on the material.

Recently, weld-free geocell has been used to strengthen a number of facilities, both in Russia and abroad. In Russia, the slope was strengthen on several sections of the Moscow Central Ring (new city electric train / metro line), on the Moscow ring road, the oil transshipment complex near Southern port (Figure 8). In the latter case, there was a case which deal with the strengthening of very steep slopes (up to 50 degrees) in the mountainous region. The geocell was filled with rubble. Recent data on monitoring of these objects showed that they are in perfect condition.

July 2016

April 2019

Figure 8. Oil transshipment complex near Southern port.

In Vietnam, the slopes of an agricultural enterprise were strengthened. A combined construction was used here, including a retaining wall with a height of 6m and a strengthening of the slope (Figure 9) with the use of weld-free geocell with a height of 5m. The design has proven its high efficiency.

February 2018

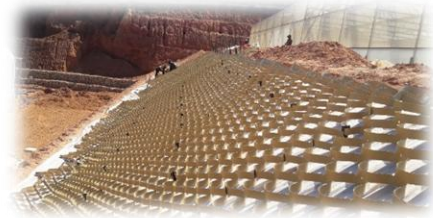

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Figure 9. Vietnam, slopes of an agricultural enterprise.

In conclusion, it has been developed instructions for the installation and installation of weld-free geocell, in addition, a video with installation instructions was posted on the YouTube channel, as well as many other materials: testing our products in independent laboratories, completed projects, and so on.

REFERENCES

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