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The use of HDPE geocells for drainage channel coating to replace reinforced concrete structures

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Abstract. Typically water conduction channels are lined with reinforced concrete structures. Often, such alternatives consume high construction costs and percentages of total investments destined for water infrastructure and maintenance. In this context, the function of engineering is to seek alternatives that allow, in a responsible and safe manner, to replace typical reinforced concrete structures, focusing on technical and economic aspects. Thus, the use of High Density Polyethylene (HDPE) geocells filled with concrete, to line channels, is intended to facilitate and accelerate the installation of this system, providing a good result, mainly due to its constructive simplicity. In addition, the technology in HDPE geocells is sufficiently stable to withstand the external forces generated on the fluid conduction structures, thus dispensing with the use of steel reinforcement, in addition to formwork, expansion joints, etc. Thus, some of the main analyzes used to demonstrate the effectiveness of the use of HDPE geocells filled with concrete for lining channels will be presented, as: resistance to extraction with cell confinement, shear stress, surface abrasion, stability due to under pressure and excessive deformations. Finally, the main benefits that these structures present in relation to conventional ones are listed, and a comparison addressing productivity, installation and costs, sustaining their success through executed cases, as well as successful cases applied to different requests in Latin America.

1 Introduction

Engineering is a discipline that constantly adapts to technological changes and growing demands for efficiency and sustainability in project development. In the most diverse sectors, such as mining, sanitation, infrastructure, energy, agriculture, among others, the use of channels coating with reinforced concrete or stone materials is common. However, this traditional practice can entail significant costs, both in the construction of new structures and in the maintenance of existing structures.

Among the challenges faced, the lack of stone material stands out, often due to the remoteness of the quarries and construction and maintenance deficiencies resulting from the lack of local specialized labor.

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However, in a development context, engineering constantly seeks alternatives that combine safety, responsibility and economy, aiming to reduce costs by making projects more efficient. In this sense, geosynthetics appear as a promising solution for plumbing, conduction and drainage projects.

Specifically, materials such as High uuDensity Polyethylene (HDPE) geocells have the potential to reduce the volume of concrete to be used, eliminate the use of steel in reinforced structures, forms and expansion joints. Representing an alternative to make projects viable, offering technical advantages and substantial savings.

2 HDPE geocells acting as lining for drainage structures

The idea of cell confinement came about in the 1980s, by the U.S. Corps of Engineers [1], giving rise to the structure known today: HDPE strips connected by ultrasonic welding beads distributed across the entire width of the strip and aligned perpendicular to the longitudinal axis. of them, which results in a structure that resembles a “hive-like” when extended. The interconnected strips form walls of a cellular confinement structure, which can be filled with materials such as vegetation substrates, soil-cement, crushed stone, mortar or concrete, depending on the request of each project. Therefore, to help engineering professionals, the international recommendation GRI GS15 [2] was developed, which specifies minimum properties that a HDPE geocell must meet to operate efficiently.

When filled with concrete, HDPE geocells form a coating that is sufficiently robust to resist the tensile forces caused by the flow and present remarkable resistance to abrasion, which is directly related to the compressive strength of the concrete used. Due to the incorporation of cells, the coating exhibits high flexibility, allowing adaptation to the different geometries used in the channels, as well as possible deformations in the section.

In general, HDPE geocells are shown to be a significant advance in the engineering of coating drainage structures, especially when filled with concrete, with their adoption in increasingly ambitious applications such as structures designed to support high-velocity flow. Unfortunately, in certain situations, these applications have been compromised by the use of inferior quality materials, which do not comply with national and international manufacturing norms and standards (such as GRI GS15 [2]), or which do not have the appropriate characteristics to interact effectively with the filling material (such as: presence of texture and perforations in the walls). This scenario has led to the occurrence of adverse results that vary between satisfactory outcomes and disastrous situations.

Due to these occurrences, several researches have been carried out in order to provide parameters and calculation references to prove the technical efficiency of HDPE geocells applied to coating drainage channels.

3 Criteria for designing drainage structures coating with HDPE geocells

Next, the main analyses and factors that will be used in the project will be presented and will guarantee the effectiveness of considering HDPE geocells as a coating system for drainage structures.

3.1 Characteristics of HDPE geocells

Due to being manufactured from polymeric materials, geocells do not adhere to concrete. Therefore, its walls must have perforations and textures that allow mechanical locking and effective interaction between the filling concrete and the cell walls.

To guarantee the mechanical imbrication between the concrete and the walls of the HDPE geocell, the contraction of the concrete installed inside it must also be controlled. The contraction of the concrete block is directly related to the opening of the geocell, since the larger the opening and size of the concrete block, the greater the contraction. The opening must be calculated so that this factor is less than the depth of the diamond texture height on the geocell walls.

The height of the geocells, when applied with concrete filling, also becomes a relevant factor. For application in channels, the CIRIA R116 report (1987) [3] is widely used, which suggests the use of a certain filling height depending on the flow speed that the structure will be subjected to, based on results of hydraulic tests carried out on coatings articulated and semi-articulated blocks.

3.2 Analysis

3.2.1 Shear Stresses

According to Porto (2006) [4], the active efforts exerted by the transported fluid are generated due to the load losses caused by the speeds or flows in certain sections and the roughness of the drainage structure. In Figure 1, we can find the components to be considered to determine the shear stress.

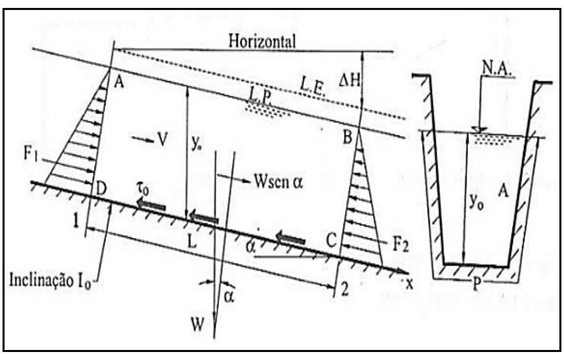

Fig. 1. Forces acting in the section. Porto (2006) [4].

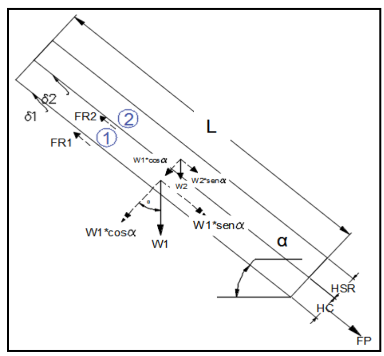

Fig. 2. Free body diagram.

$$\sum F_x = F_1 + \gamma\, A\, L\, sen\alpha - F_2 - \tau_0\, P\, L = 0 \quad (1)$$

where:

γ : Volumetric weight of the fluid. (kN/m³).
A : Wet area. (m²).
L : Length (m).
τ_0: Shear stress. (kN/m²).
P : Wet perimeter. (m).

After determining the shear stress on the coating, using the principle of the free body diagram, it is possible to determine the resistant efforts necessary to stabilize the structure, as well as determining the safety factor for it.

3.2.2 Block extraction with cell confinement

To quantify the force required to pull out blocks inside the geocells, extraction tests are carried out with geocells filled with concrete, demonstrating that the rigid, perforated and textured HDPE walls allow the mechanical locking of the coarse and fine concrete aggregate with the walls of the geocell, so that, to be able to extract the block, the force applied must be large enough to first break the aggregate and concrete.

a) Fill extraction test

b) Extraction test result

Fig. 3. Fill extraction text.

For comparison purposes, pullout tests were also carried out on conventional concrete slabs. What can be observed is that the way the concrete structure ruptures, when it reaches its tension limit, the plate breaks completely, reaching the areas underlying the applied pressure, causing cracks and deep cracks, which makes it unfeasible to carry out of specific/partial repairs, requiring total replacement of the structure.

3.2.3 Surface abrasion

Abrasion resistance is the ability of concrete to resist surface wear efforts, which, in this case, will be caused by the flow passing over it. Due to several studies and effective practices over the years, which have proven the efficiency of concrete abrasion for this purpose, we can mention the Mexican technical regulations [5] expressed in Table 1, which demonstrates the resistance necessary for concrete to withstand the abrasive effects arising from the flow in a channel, relating it to the speeds that the channel will be subjected to.

Table 1. Concrete compressive strength versus flow velocity [5].

Compressive Strength At 28 Days (kg/cm²)	**Flow Velocity (m/s)**
f'c = 90	2,8
f'c = 110	4,4
f'c = 130	5,8
f'c = 170	6,6
f'c = 210	7,4

3.2.4 Sub-pressures stability

For projects where there is a possibility of sub-pressures behind the coating on HDPE geocells, analyzes are carried out against this effect. The analysis is carried out in order to compare the sub-pressure applied under an individual cell and compare it with the resistance to extraction of the concrete block obtained in tests as demonstrated in Item 3.2.2. If the sub-pressure exceeds the extraction force given in the laboratory for the cell model specified in the project, a pressure relief system must be implemented as a solution.

3.2.5 Excessive deformations

This verification takes place through the efforts acting on the structure that can result in settlements (Hs) compromising its behavior, as shown in Figure 4.

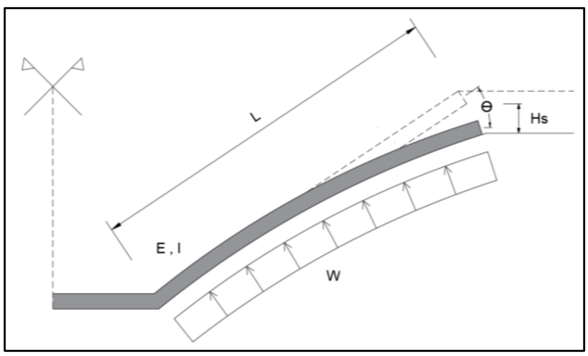

Fig. 4. Material extraction test inside geocells.

To determine the force applied to the deflected coating surface, we use the typical expression for conventional concrete or mortar coatings, taking as a basis the modulus of elasticity of the coating and the geometric parameters of the slope, which can be estimated by the expression in continuity.

$$W = 24\, E\, I \frac{\theta}{L^3} \quad (2)$$

where:
W: Pressure on the deflected slope. (kPa).
E : Modulus of elasticity. (kPa).
I : Section inertia. (m^4).
θ : Protection turning angle. (°).
L : Inclined slope length. (m).

4 Comparison between coating of drainage structures

Due to the successful application of HDPE geocells as channel coating, aiming to demonstrate the advantages of using the material reflected in its installation costs and productivity, a comparison was carried out between HDPE geocell solutions versus cast-in-situ reinforced concrete, demonstrated below. To achieve this, for both sections, the following premises were considered:

- Variations in flow rates between 3 and 16 m³/s and consequent variation in the geometry of the sections (base and height).
- Trapezoidal section with slope inclination of 1H : 1V.
- Concrete roughness of 0.017.
- Longitudinal length of 100 m.
- 5% slope.

For the composition of costs and productivity, as shown in Table 2 and Table 3 respectively, data from the SICRO [6] synthetic reports and the TCPO [7] report were used.

Table 2. Cost comparison between HDPE geocells and cast-in-situ reinforced concrete.

Section	Flow Rate Section	Section Perimeter	Material ($/m²)	
	m³/s	m	Geocell	Concrete
1	Q ≤ 3	2,70	$ 14,29	$ 33,50
2	3 < Q ≤ 7	3,56	$ 18,34	$ 41,62
3	7 < Q ≤ 11	4,15	$ 24,09	$ 57,84
4	11 < Q ≤ 16	4,83	$ 29,95	$ 74,07

Table 3. Productivity comparison between HDPE geocells and cast-in-situ reinforced concrete.

Section	Flow Rate Section	Section Perimeter	Productivity (Man-hours/m²)	
	m³/s	m	Geocell	Concrete
1	Q ≤ 3	2,70	0,008	0,113
2	3 < Q ≤ 7	3,56	0,010	0,150
3	7 < Q ≤ 11	4,15	0,015	0,225
4	11 < Q ≤ 16	4,83	0,040	0,300

5 Successful cases of application of HDPE geocells

With the advancement of technologies, whether in the development of calculation methodologies, or in the manufacture of special/tailor-made materials, it has increasingly influenced engineers in the search for the use of HDPE geocells for coating drainage structures. Next, some historical cases will be presented, carried out in Brazil, where HDPE geocells filled with concrete were used.

In Figure 5, we can find an overflow channel, made with HDPE geocells filled with concrete, in Itabirito, Minas Gerais. In this case, the project was initially designed in reinforced concrete. However, due to the season's heavy rains, the dam entered a state of emergency, which required urgency in carrying out the channel's lining and protection system. The solution with HDPE geocells was adopted due to the construction ease and agility that the solution provided, enabling construction within the estimated deadline, meeting the client's needs.

Fig. 5. Spillway Structure of a Tailings Dam, Minas Gerais.

In Figure 6, we see a case of the perimeter drainage channel of a mining company in Congonhas, Minas Gerais. In the same way as in the first case, the project was initially designed in reinforced concrete, however, due to the speed of the geocell installation process, the client concluded that they were the most advantageous option, technically and economically, for the project.

Fig. 4. Perimeter Canal, Minas Gerais.

6 Conclusion

High Density Polyethylene (HDPE) geocells represent a significant innovation in civil engineering. The variety of options available on the market offers designers the flexibility necessary to choose the most suitable material for each project, taking into account its particularities and challenges.

One of the main advantages of these geocells is the speed of installation and the elimination of the need for specialized labor. Initially, when purchasing materials, it is possible to observe savings of up to 147% in relation to conventional concrete structures, and at the end of the work the benefits are even more notable, reaching potential savings for the client of up to 1,100%. in installation costs, with geocells being up to 1,400% more efficient in this process.

Furthermore, the active support of researchers and engineers in this area has provided customers with detailed technical information, improved calculation methods and high-quality materials. This guarantees lasting performance and a long service life of structures built with HDPE geocells.

With a growing list of successful work, we can confidently say that the advantages of HDPE geocells in hydraulic applications will last over time. Modern civil engineering has a valuable tool at its disposal to improve the efficiency, economy and sustainability of drainage projects.

References

1. J.W. Robinson, *Full-Scale Evaluation of Multi-axial Geogrids in Road Applications*, E **1**, USA (2022).
2. Standard Specification, *Test Methods, Test Properties and Testing Frequency for Geocells Made From High Density Polyethylene (HDPE) Strips*, Geosynthetic Institute, GRI-GS15, 1-9 (2016).
3. H.W.M. Hewlett, L.A. Boorman, M.E. Bramley, *Design of Reinforced Grass Waterways, London*, England, 116 (1987).
4. R.D.M. Porto, Hidráulica Básica, E **4**, 519 (2006).
5. D.F. MX, *Normas Técnicas Complementarias para el Diseño y Ejecución de Obras e Instalaciones Hidráulicas,* State of Mexico, Mexico (2004).
6. DNIT, *Sistema de Custos Referenciais de Obras – SICRO,* of the Minas Gerais, Brazil (2023)
7. PINI Editora, Tabelas de Composições de Preços para Orcamentos – TCPO, E **15** (2017).
8. G. Fierro, *Channel Revestment with Celullar Confinement System and Shotcret in Mining Projects,* of the 4th Pan American Conference on Geosynthetics, GEOAMERICAS, Rio de Janeiro, Brazil, 1-9 (2020).
9. W.J. Caressato, *Use of HDPE Geocells to Replace Rip Rap and Reinforced Concrete in Superficial Drainage Structures in Photovoltaic Power Stations*, of the 4th Pan American Conference on Geosynthetics, GEOAMERICAS, Rio de Janeiro, Brazil, 1-9, (2020).
10. W.J. Caressato, C.A. Centurión, *Revestimento com Geocélulas de PEAD Preenchidas com Concreto em Substituição a Estruturas Rígidas de Concreto Armado para Drenagem Superficial em Pilha Estétil*, of the 19th Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, COBRAMSEG, Bahia, Brazil, 1-7 (2018).
11. W.J. Caressato, B. Todescan, L.T. Andrade, *Uso de Geocélulas PEAD Preenchidas com Material Granular para Sistemas de Drenagem Superficial*, of the 10th Congresso Brasileiro de Geotecnia Ambiental, REGEO, Bahia, Brazil, 1-6 (2023).