Retaining walls with high weight concrete blocks in association with geosynthetics

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Abstract. Geosynthetic reinforced retaining walls with cellular facing are well-known and mastered technics commonly used in France and around the world. This technic combines cellular blocks (such as concrete, gabion baskets…) with high modulus reinforcement geosynthetics and allows the retaining wall to resists stresses on very high heights. However, the installation procedure of these blocks knows some limits for great projects such as the duration of installation or how to deal with a draining system behind the facing. That's why the idea of the creation of a block with new size, new weight and new composition came on the table. This concrete block with almost 1 m² of facing area per block and 700 kg empty allows the use of an hybrid solution part-weight/part-geosynthetic reinforcement while ensuring an extremely fast and easy on-site installation with classical lifting engines.

1. Introduction

The idea of this new block was born a few years ago in a compagnie expert in cellular blocks for retaining walls in France. The aim was to respond to several problematics they encountered with the classical solution of smaller concrete blocks carried by hand on the working site, such as the duration of installation or the dealing with curves for the block.

This creation was thought in order to maximize the ease of installation and the quality of the product. Everything has been thought in order to fit into the European standards and to present an improved geotechnical approach of retaining walls.

This article will first detail the geometry of the block and the modelization which has been performed in order to anticipate the dealing with curves. Then, the structural data of the block, including the concrete and the framework, will be introduced along with their classification in the standards. At last, a geotechnical overview will be made to explain the features of this new block for the problematics of drainage and pullout resistance. A small presentation of the first working site will end this article.

2. Geometry of the high weight block

2.1. Rough geometrical data

The geometry of the high weight block allows the lay-out of almost 1m² of facing per block. The aim was to create an element heavy enough to be used in retaining walls, lifted on site with specialized engines but very easy and fats to lay out in rows. The geometry has been especially studied in order to allow the stack of the blocks one on another without any difficulties. Moreover, the implementation of the reinforcement geosynthetic is eased by the special compartment designed at this effect. It can prevent problems such has wrong installation by unexperimented team on the working site. The figure 1 shows the geometry of the element.

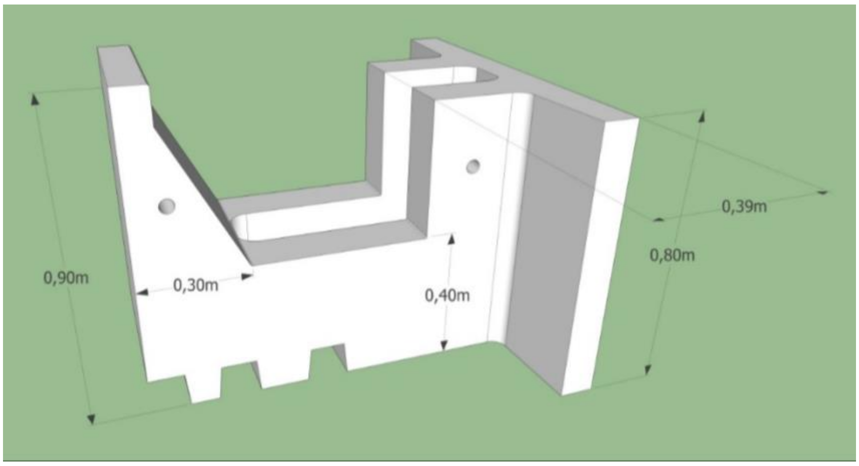

Figure 1. Geometry of the element.

All these patented elements stack on top of each other and are then combined with embankment techniques in order to create supports combining the gravitational effect of the elements associated with a reinforced embankment and with geosynthetics. Their geometry makes it possible to adapt to variations in fruit and wall curvatures, up to the realization of 90 ° angles.

Each element is provided with a notch system blocking the upper blocks on the respected rows. This type of notch (patented) guarantees perfect resistance to horizontal pressure and avoids lateral and horizontal movements. It also allows an easier installation on the working site. The seat under the first row is poor concrete, just to have a proper seat to begin the layout. The elements are placed in touch horizontally. The elements of the following rows interlock with each other and the voids are filled with draining granular fill (ballast type) progressively. The elements are installed by lifting devices and a three-strand sling (Figure 2), using three arteon hooks sealed in the element (two at the front and one at the rear).

Figure 2. Illustration of the block-lifting process.

2.2. Curve modelization

One of the aim of the conception of this element was to create an element able to deal with curves better than other scale-shape concrete elements. A modelzation of the curves has been done to evaluate the ability of the element to be deployed on concave or convex curves, right angles, etc. The minimal radius to have a right angle with a convex surface is 2,56m, which is better than most traditional ways on the subject (Figure 3).

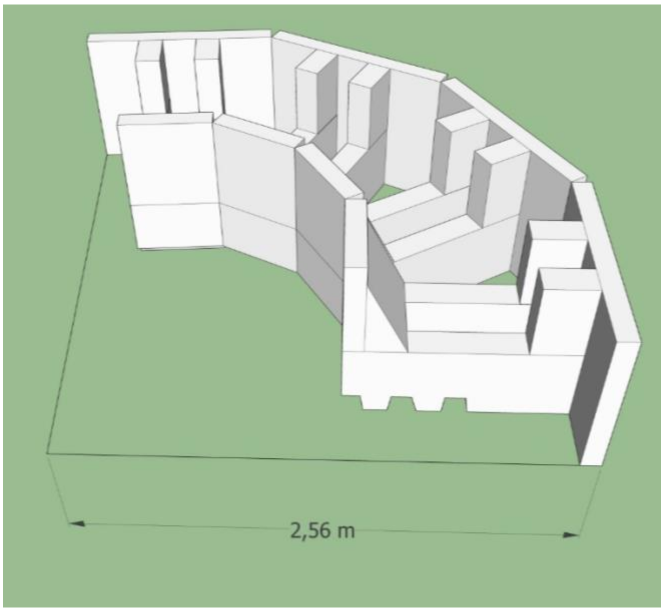

Figure 3. Convex radius to have a right angle.

This modelization has been verified on a test working site with real blocks. This working site had two main objectives, validate the production process and verify the curve modelization which had been prepared in the conception phase. Figure 4 has been taken from this test working site.

Figure 4. Test working site.

This test proved that the block was ready for commercial purpose and was satisfying every requirement in terms of production process and modelization which had been made on the subject. Moreover, even if it was an internal test for this new block, the first approach of the installation was very encouraging for the rest of the development.

3. Structural data

3.1. Manufacturing

The elements are prefabricated in molds of six pieces face down. The steels are placed first then the concrete is poured inside. A matrix can be placed at the bottom of the mold in order to reproduce different esthetic aspects. After 24 hours of drying, the elements are removed from the mold and then stored. The matrix can be in a several shape to satisfy the esthetic requirements of the project, such as shown in the figure 5.

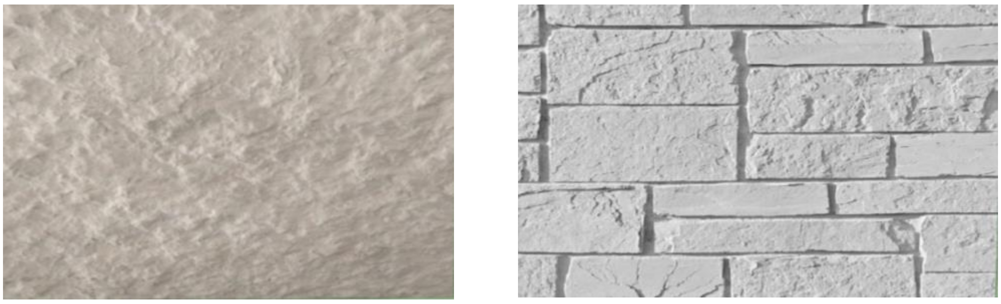

Figure 5. Different matrix for the block.

This ability of esthetic diversity is already appreciated by the project designers and makes one of the greatest strengths of the solution. Nowadays, the design of a project must be approved by an architect or landscape expert before the beginning of works.

3.2. Concrete class exposure

Within the framework of the dimensioning of the blocks, we propose to retain two categories of exposure. A category called aggressive and a so-called normal. The exposure classes in the so-called normal category are the exposure classes [3] up to:

- Carbonation induced corrosion: XC4
- Corrosion induced by chlorides: XD1
- Corrosion induced by chlorides present in seawater: XS1
- Thaw freeze attack: XF1 or XF3
- The exposure classes in the so-called aggressive category are the exposure classes up to:
- Corrosion induced by carbonation: XC4
- Corrosion induced by chlorides: XD3
- Corrosion induced by chlorides present in seawater: XS3
- Thaw freeze attack: XF2 or XF4

3.3. Concrete used in the block

Two strength classes have been selected for concrete, corresponding to the two exposure categories mentioned above, with a class N cement. For the so-called normal element category, the strength class of concrete will be C30 / 37. For the so-called aggressive element category, the concrete resistance class will be C35 / 45 (Table 1). These categories are standard for items placed in stock. However, the mechanical characteristics of the concrete may vary depending on the project or according to the client.

Table 1. Concrete classification details

Designation	Value	
Concrete class	C30/37	C35/45
Mass per unit area	$\rho = 2500\ kg/m^3$	$\rho = 2500\ kg/m^3$
Poisson Coefficient	Uncracked concrete: $\upsilon = 0.2$ Cracked concrete: $\upsilon = 0$	Uncracked concrete: $\upsilon = 0.2$ Cracked concrete: $\upsilon = 0$
Pressure resistance	$f_{ck} = 30\ MPa$ $(f_{ck,cube} = 37\ MPa)$	$f_{ck} = 35\ MPa$ $(f_{ck,cube} = 45\ MPa)$
Tensile strength (average)	$f_{ctm} = 2.9\ MPa$	$f_{ctm} = 3.2\ MPa$
Elasticity modulus (short term)	$E_{cm} = 33000\ MPa$	$E_{cm} = 34000\ MPa$
Elasticity modulus (long term)	$E_{c,eff} = 15100\ MPa$	$E_{c,eff} = 17000\ MPa$
Deformation on compressive strain	$\varepsilon_{cu2} = 3.5‰$	$\varepsilon_{cu2} = 3.5‰$
Amortization coefficient	7%	7%
Thermic expansion coefficient	$\alpha_c = 10^{-5}\ /°C$	$\alpha_c = 10^{-5}\ /°C$

3.4. Steel framework

Steel are usually of Fe500 type.

Table 2. Steel properties

Property	Value
Mass per unit area	$\rho = 7850\ kg/m^3$
Pressure resistance	$f_{yk} = 500\ MPa$
Ultimate deformation	$\varepsilon_{uk} \geq 5\%$ (ductility class B)
Elasticity	$E_s = 210\ 000\ MPa$
Thermic dilating coefficient	$\alpha_s = 10^{-5}\ /°C$

Datas used for calculation are usually as the values in table 3.

Table 3. Reinforced concrete caracteristics

Environment	Exposure classes	Structural classes	$C_{min\ dur}$ [mm]
Normal	XC4, XS1, XD1	S4	35
Agressif	XC4, XS3, XD3	S4	45

The structural class S6 is for 100 years of use. We can lower the structural class to S4 if the project is able to accept it.

The coating (c_{nom}) is calculated the way shown below:

$$c_{nom} = c_{min} + \Delta c_{dev}$$

With:

- $c_{min} = \max\{c_{min\ b}; c_{min\ dur} + \Delta c_{dur\ \gamma} + \Delta c_{dur\ st} + \Delta c_{dur\ add}; 10\ mm\} \Delta c_{dev} = 5\ mm$

Table 4. Coating values

Environment	C_{nom} [mm]
Normal	40
Agressive	50

4. Geotechnical overview

4.1. Drainage inside the block

The fill with granular draining material (ballast) inside the block allows a draining layer on the facing which can avoid disorders due to water pressure inside the embankment. This drainage material must be protected from contamination by a geotextile in order to keep the hydraulic properties.

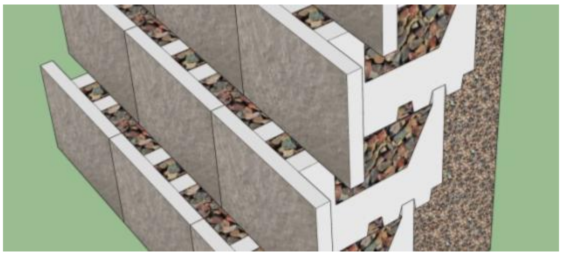

Figure 6. Ballast fill material.

4.2. Geocomposite used in reinforcement and separation

The idea of using a geocomposite combining the separation function of an anti-contamination geotextile and the reinforcement function of a geogrid came with the necessity of the simplification of the installation. The great aim of the whole conception of the solution was to ease as much as possible the installation on the working site, that's why the layout of one layer of geotextile instead of two was a necessity in this state of mind.

The issue was to find a woven geotextile with a small enough opening size to allow the separation between soils with also a high reinforcement capacity. That's why a woven geotextile associated with high tenacity cables has been chosen.

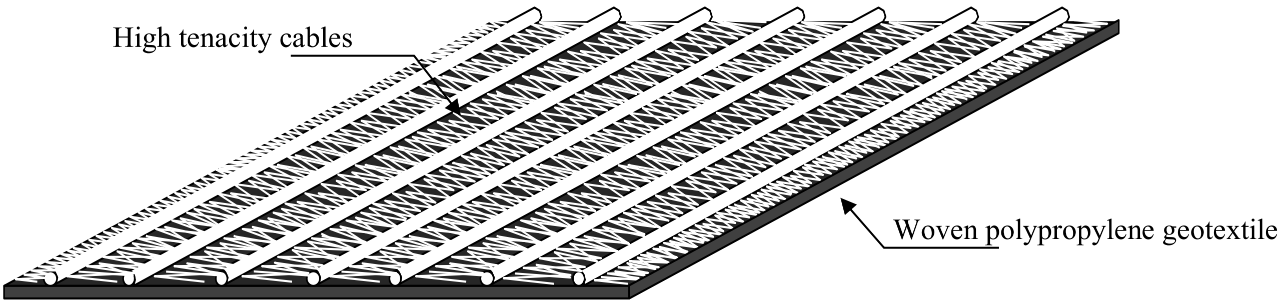

Figure 7. Structure of the geocomposite.

The pros of this system are:

- The ability to use several materials for the cables according to their properties, such as polyester for most cases but also PVA for chemical resistance and low elongation
- A controlled opening size thanks to a manufactured product, and so on an enhance filtration separation capacity around the fill in ballast inside the block
- The back face of the block is exactly 80cm height for every block. It corresponds to the maximal vertical spacing limit asked determined by the standard NF G 38-064 [1] and allows the future retaining walls to fit into the French and European standards [1] [2]. We still can nuance this affirmation: the standard accepts until 1m of vertical spacing if the facing dispositive allows a local retaining function. In the case of such a high weight block, it would be the case

4.3. Warp-knitting technology

The warp knitting technology used to create this geocomposite allows the use of right pre-tensed cables able to be put on tensile strength immediately without the small deformation seen on some classic woven geotextile, such as shown on the figure 8.

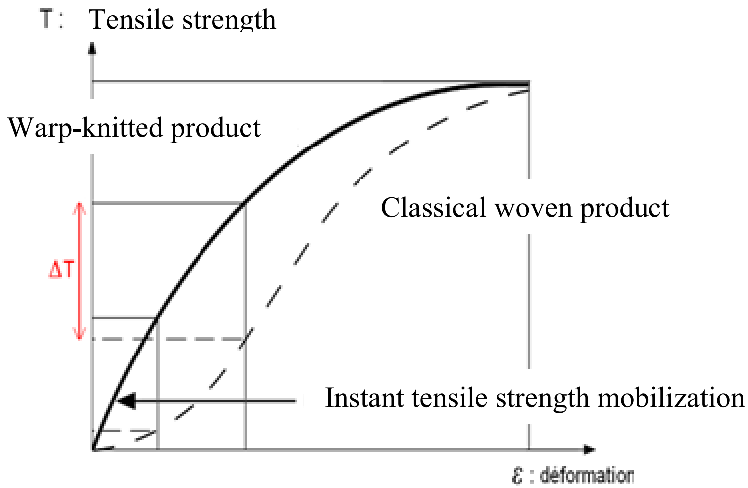

Figure 8. Tensile strength/elongation curve.

The final tensile strength being decided by the diameter of the cables used, this kind of geocomposites can level up to 1800kN/m in tensile strength, which is far beyond any requirement in retaining walls design. Moreover, the woven textile associated with the cables can offer protection against the installation damages induced by the compaction phase, by being on top during the layout.

4.4. Pull-out resistance of the wall

One issue that came up during the process of conception was the pullout resistance of the block inside the wall. How to evaluate it? And how could we be able to verify for every project this resistance? It is known, after tests done on classical small blocks walls, that the placement and the kind of the reinforcement geosynthetic bring a mechanical link with the technical embankment behind. That's why in such a case of high weight block, we have to think deeply on how to modelize this pullout strength and resistance, and an anchoring calculation similar to the anchoring trench calculation we can find in the NF G 38-067 came up. The idea came with the detail of the geometry inside the block in comparison with a classical anchoring trench (Figure 9).

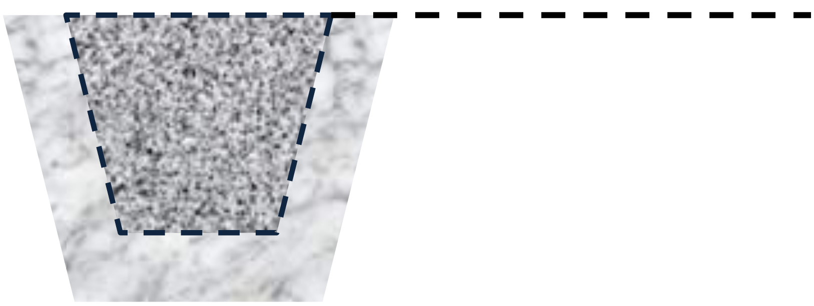

Figure 9. Geometry of the wrip-wrapped ballast inside the block.

The aim is to consider this wrip-wrapped ballast like a technical fill inside the anchoring trench inside the block. We need for this kind of calculation of the friction data of the interfaces geosynthetic/concrete and geosynthetic/ballast, the geometry of the trench (always the same, as the block geometry is controlled in factory) and mainly the pullout strength applying inside the geosynthetic. This way, by making a comparison between the anchoring resistance and the pullout strength, we could in theory get a safety factor for every row of block.

5. First working site in France

A first working site has been realized in France in Aurillac a few month ago. This was a first trial with a contractor who was laying out the full solution, and one of the great results of this first realization was the final yield of the layout phase: around 140m² of facing layed out all included (embankment and geosynthetic too) in one and a half day. This confirm the number one advantage of the solution: the swiftness of execution. Figure 10 present the final work.

Figure 10. Final work.

6. Conclusion

To conclude, we can say that the combination between concrete blocks and reinforcement geosynthetics is clearly not an update: this is a technic which has been developed and used for decades around the world, and which is more than confirmed. Although the fundamental technic remains the same in terms of calculation and profile, the main asset of this new development is the gigantic size of the block. In addition of the high weight of this block, which is an aid for the general stability of the project, the clever geometry allows the association with geosynthetic and drainage on a simple base. Moreover, the study about the ease of layout was proved right with some working site examples.
What is to be kept from this article is that there are ways to combine geotechnical coherence and stability in calculation with ease of layout for contractors: mainly, the necessity of drainage, filtration and reinforcement are the points which take time to install on the field, but not in this case.

One aspect which has not been highlighted in this article is the aspect of safety: it is true that wrip-wrapped walls with framework facings are more and more installed in European countries in order to allow a fine vegetal aspect on long term duration. However, the installation is often contested by contractors who are worried about the safety of their personal on site. This kind of contests from the contractors has been identified years ago, and this kind of solution involving heavy machinery and limiting the access of labor force on the edge of the embankment is an insurance of safety on the working site, especially on high heights which are opportune to work accidents.

References

[1] NF G 38-064 (2016) - Use of geotextiles and geotextiles-related products - Inclined walls and strengthened slopes in soils reinforced by geosynthetic sheets - Justification of dimensioning and design elements

[2] NF G 94-270 (2009) - Geotechnical design - Retaining structures

[3] NF EN 1992 (2006), Eurocode 2 - Design of concrete structure