Use of Drainage Geocomposite in the internal drainage system of dams in replacement of granular material

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ABSTRACT
Piping and liquefaction are the two main causes that lead a dam to collapse and are related to the increase of pore pressure in the interior of the massif due to the non-direction of the water flow, that is, the inefficiency or non-existence of the internal drainage system. This system serves to relieve pore pressure inside the mass of a dam, as it directs the flow downstream of the structure, thus avoiding saturation of the massif. Currently, the most used materials for the composition of the internal drainage system are granular materials (gravel and sand). However, there are geosynthetics, such as drainage geocomposites, that fulfill the same function as granular materials: filtration and drainage. When comparing the two systems, the use of drainage geocomposite is more advantageous in terms of cost-benefit, execution and transportation. Although geosynthetics have several advantages, compared to the conventional drainage system with granular material, it is still little used and this is possibly due to the insecurity of professionals in using an alternative method with a low history of use.

Keywords: Drainage Geocomposite, Geosynthetics, Granular material, Cost, Execution, Transportation.

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INTRODUCTION

Dams are physical structures built with the purpose of containing water for supply, generating electricity, as well as accumulating tailings (MOREIRA, 1981 *apud* AZEVEDO, 2005). In view of this, dams play an important socioeconomic role, however, they can cause several negative impacts, including environmental, social and economic (VIANNA, 2015).

According to Azevedo (2005), dams need to be efficient and safe, in view of the tragic consequences they bring in the event of ruptures. Water is one of the main problems of geotechnical engineering, since, if not controlled, it can cause erosion, carrying fines, compromising the stability of the structure.

To solve such problems, internal drainage systems are used to ensure the safety of dams, as they relieve internal pressures and prevent saturation of the massif (PETROCELLI, 2019).

Currently, the most used material for the composition of the internal drainage system are granular materials (such as sand and gravel), in the composition of drainage mats and vertical filters. However, the market offers alternatives with the function of filtering and draining the water from the internal flow of the dams, as is the case of drainage geocomposites. According to IGS (*International Geosynthetics Society*) geosynthetics are flat materials made of polymers, whether natural or not, used in contact with the ground within engineering works. In this context, according to CARNEIRO (2009), in order for geosynthetics to fulfill their function in internal drainage, the size of their opening must be minimal enough to prevent the passage of solid particles into the drains, while allowing the free passage of water.

The use of geosynthetics in dams as a drainage layer began in the 1970s, with the construction of "Frauenau Dam" in Germany and "Hans Stridjon Dam" in South Africa (VERTEMATTI, 2004). At the same time, geotextiles were being introduced in Brazil as drainage devices on highways.

Granular materials, although still the most used in internal drainage of dams, are a high-cost material, since the higher the design flow, the greater the required thickness of material. In addition, in hard-to-acquire locations, the average transport distance is high, increasing its cost due to transportation. Thus, this article aims to present the comparative advantages of cost and execution of drainage geocomposites, when used in the replacement of granular material for the composition of the internal drainage system of dams. Although they are still little used and publicized, they present satisfactory performance for this function.

MATERIAL AND METHODS

For the elaboration of this article, it was necessary to Extensive consultation with geosynthetics suppliers and a literature review on the comparative advantages of geosynthetics over granular meterial in terms of execution, transportation and cost. After this research, the design of an internal drainage system, with both materials, for the same section of a hypothetical dam was carried out, for comparative purposes.

The design flow rate for system sizing was obtained through percolation analysis with the aid of Rocscience's Slide2® program. The permeability parameters of the compacted mass and the foundation material, used for the elaboration of this analysis, were based on CRUZ (2004).

The design flow rate was used to calculate the thickness of granular material, applying a safety factor of 10, according to the recommendation of the ABNT NBR 13028:2017 standard, through Darcy's law, expressed by Equation 1.

$$Q = k\ i\ A \qquad (1)$$

Where:

Q: design flow rate (m^3/s);

k: permeability of the drainage material (m/s); I: hydraulic gradient;

A: drainage area (m^2).

The geocomposite chosen to compose the geosynthetic drainage system was MacDrain® 2R5 20.2, from Maccaferri. It has a drainage core formed by a high-density polyethylene geonet thermo-welded at all its points of contact with two non-woven geotextiles. The product has high compressive strength and high transmissivity. Figure 1 shows the product and Figure 2 shows its technical sheet.

Figure 1. MacDrain® 2R5 20.2, by Maccaferri

Figure 2. MacDrain® 2R5 20.2 datasheet.

Propriedades hidráulicas do geotêxtil			2R5 20.2
Permeabilidade	cm/s	ASTM D4491	0,3
Abertura aparente (AOS)	mm	ASTM D4751	0,16

Capacidade de vazão						
ASTM D 4716	Drenagem horizontal				Drenagem vertical	
Gradiente hidráulico	i = 0.01		i = 0.10		i = 1.00	
Pressão	(l/s)/m	(l/h)/m	(l/s)/m	(l/h)/m	(l/s)/m	(l/h)/m
10 kPa	0,09	339	0,30	1097	1,66	5974
50 kPa	0,07	258	0,18	656	0,85	3066
100 kPa	0,05	165	0,15	532	0,74	2670

Propriedades físicas Geocomposto			2R5 20.2
Gramatura	g/m²	ISO 9864	1400
Espessura	mm	ISO 9863	≥5

Apresentação do rolo		2R5 20.2
Comprimento	m	25
Largura	m	2

The methodology for calculating the drainage system consisting of geosynthetics consists of the verification of physical properties of the materials, such as mesh opening, tensile strength, puncture and permeability, in order to verify if the pre-chosen material meets the needs imposed by the design boundary conditions. To this end, the teaching was based on Wavin's book: "Infrastructure projects with geosynthetics" (2022).

The first check is the comparison between the required permissiveness and the permissible one indicated in the product catalogue, using Equation 2.

$$\Psi req= \frac{Q}{\frac{\Delta h}{L} H} \qquad (2)$$

Where:

Ψreq:required permittivity of Geotextile, k/t. (s-1)

Q: calculated total flow rate to evacuate (m/s²).

Δh: hydraulic load, which is equal to the height of the Geocomposite (m).

H: height of the Geocomposite (m).

L: length of the drainage span in question (m).

Then, the required flow rate is verified in relation to the design flow, according to Equation 3.

$$Qwreq = \frac{Qt}{L} \qquad (3)$$

Where:

Qt = Total project flow rate (m/s²);

L = Length of Geocomposite (m).

RESULTS AND DISCUSSIONS

Among the geosynthetics options available on the market that fulfill the function of filter and drain, to replace granular material in drainage the one that best fits is the drainage geocomposite.

The drainage geocomposite consists of the junction of two geosynthetics: geotextile and geonet. At this junction, the purpose of the getextile is to prevent the passage of solid particles into the geogrid, which would lead to in blockage this. At the same time, the geonet acts as a drain, allowing the free passage of water and conducting the flow downstream of the structure. In this context, the geotextile would take the place of the transition with sand and the geonet would replace the drainage material, as in the case of gravel.

MATERIAL AND TRANSPORTATION COSTS

In a survey conducted with geosynthetics suppliers in the region of Belo Horizonte, Minas Gerais, the average cost of drainage geocomposite is R$ 40.00 reais. The transport is carried out in a conventional way, by means of trucks and transported in the form of coils. According to the suppliers, the freight of the delivery of the product is calculated considering a value of R$ 4.00 reais per km.

As for granular materials, the cost per ton, according to the cost breakdown table of CAIXA, SINAPI (MG. Oct/2022) , varies according to the size of the grains, as shown in Table 1.

Table 1. Granular material costs – SINAPI

Material	Value
Fine Sand	R$ 100,00
Medium Sand	R$ 100,00
Coarse sand	R$ 101,30
Gravel 00	R$ 121,25
Gravel 01	R$ 105,02

As for transporting the granular material, it must be carried out in a dump truck, with a protective screen. The value of the transport, according to the cost breakdown table of the DNIT – SICRO (MG, nov/2016) is R$ 0.76 reais per t/km.

EXECUTION

For the execution of the internal drainage system of a dam with geosynthetics, it is not necessary to have specialized labor, only monitoring during the execution and care with the handling of the material in order to avoid damage. For this, according to the Brazilian Manual of Geosynthetics, any sharp object must be removed from the surface on which it will be installed. In addition, the height of soil fall on the geocomposite must be limited to avoid damage, such as tears in the material.

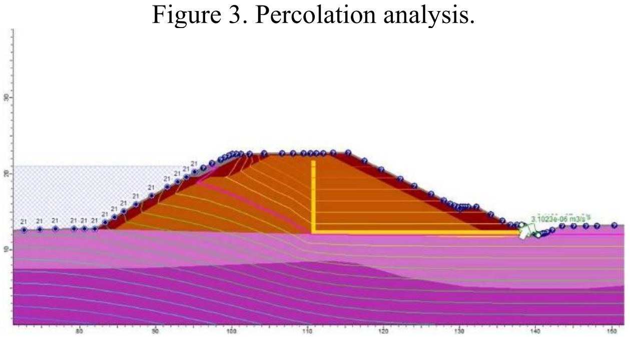
As for the execution with granular material, special care must be taken in order to avoid contamination of the material that will be used in the drainage system by particulate matter, especially in the rainy season. In case of contamination, the material must be removed and replaced. In addition, quality control at the time of execution of the drainage system with granular material is of paramount importance. In this sense, particle size tests must be performed in order to ensure that they present a particle size curve according to the limits established and presented in the project. Briefly, it is important to ensure that the properties of the materials are within those required in the project, avoid segregation and contamination of the material that may alter its properties, ensuring quality in the execution of the system.

SIZING

After collecting the information presented in the previous topics, for comparative-quantitative purposes, the design of an internal drainage system for a dam with both granular and geocomposite drainage materials was carried out.

Based on this, first, with the aid of the Slide2 software, a percolation analysis was performed in a representative section of the thalweg of a hypothetical dam, in order to obtain the maximum flow at the drain outlet for later dimensioning of the internal drainage system of both solutions compared in this work. Figure 3 shows the flow lines and the flow at the outlet of the drainage mat obtained through percolation analysis, which is 3.1 x 10-6 m^3/s/m

Figure 3. Percolation analysis.



Dimensioning with granular material

According to ABNT NBR13028:2017, from the flow rates obtained in the percolation analyses carried out in the dam and, considering a minimum safety factor of 10, the dimensions and thicknesses of the drainage layer are determined. However, according to the civil design criteria elaborated by Eletrobrás in 2009, for constructive reasons involving machinery, there are minimum dimensions that drainage devices must have, namely:

a) vertical or inclined filter: 0.60 m;

b) horizontal filter: thickness of 0.30 m;

c) foundation drainage trench: width 0.60 m;

d) Relief pits: diameter of 0.10 m.

The drainage system acts to direct the percolation flow through the massif, redirects the flow lines and thus prevents the occurrence of internal erosion, pipping, and increased pore oppression (FARIA, 2019). From studies related to cohesive and non-cohesive soils when subjected to large percolation forces, the engineer Karl Von Terzaghi, in 1943, determined criteria for the design of filters, relating the particle size curve of the materials. Therefore, it defined two criteria for the adoption of the appropriate material for the composition of the internal drainage system:

a) The material that makes up the filter must be able to retain and prevent the percolation of particles from the mass through it. That is, the material must be well graded, so that the voids formed are small enough to retain particles from the base soil;

b) The filter material must be permeable enough to allow water to flow freely without creating pore pressure accretions.

In the master's thesis, prepared by Silva (2016), there are relationships established by Terzaghi considering the diameter of the particles of the materials, so that the filter satisfies the aforementioned criteria. With regard to the retention criterion, the diameter D15 (mm), which corresponds to the diameter of the sieve that passes 15% of the particles, should not exceed four times the diameter that represents 85% of the material passing through the thinnest layer of the base soil, d85, then D15/ d85 B $\leq$ 4. To satisfy the drainage criterion, and to allow the free flow of water, draining it from the massif, the filter must have sufficient hydraulic conductivity. For this to occur, Terzaghi determines that the ratio between the diameter D15 (mm) of the filter and the diameter corresponding to 15% of the particles of the massif, d15 (mm), must be greater than or equal to four, that is, D15/d15 B $\geq$ 4.

In addition, the material that composes the filter must follow the uniformity criterion, where the ratio between the interface of the filter's fine granular material over that of coarse material is less than or equal to 10, where D60 /D10 $\leq$ 10. Also, the percentage of fine material, passing through the #200 sieve (0.074 mm), should not be more than 2%.

After choosing the material that meets the above criteria, it is possible to carry out the design of the drainage system with granular material.

Thus, considering the permeability of the On the basis of the carpet drainage material (gravel 01) of 0.15 m/s (k), 30 m of the belt extension (Ltap) and the outlet flow of 3.1 x 10-6 m^3/s/m obtained in the percolation (Q), it is possible to determine the thickness of the filter (B) using granular material through Darcy's law, since:

$$Q = k\ i\ A$$
$$Q = k \frac{B}{Ltap} B * 1$$
$$Q = k \frac{B2}{Ltap}$$

Thus, by substituting the values in the formulation and considering a safety factor of 10, it is obtained that the necessary thickness of the mat to meet the design flow rate is 0.026 m, as shown in Equation 4.

$$3{,}1x10^{-6} = 0{,}15 \frac{B^2}{30} = 0{,}025\ m \qquad (4)$$

However, for construction reasons, the gravel layer must have a minimum thickness of 0.30 m. The vertical filter is composed of sand and must have a minimum thickness of 0.60 m, due to the machinery used in the excavation for its execution. In addition, there must be a 0.20 m sand transition layer between the gravel of the horizontal drain and the massif and foundation, thus being a sandwich-type drainage mat – sand, gravel and sand – as shown in the detail of Figure 4.

Figure 4. Detail of the vertical filter and draining mat.

Considering the dimensions mentioned above, it is possible to calculate the volume of each material that in internal drainage. Thus, 3432 m³ of sand and 1764 m³ of gravel are required. Taking into account the prices presented in item 3.1 per m³, being R$105.02 for a 01 gravel and R$100.00 for sand, the cost of material for the work would be R$528,455.28 (Table 2).

Table 2. Total value of granular material for drainage

Material	Volume (m^3)	Cost (R$)
Sand	3432,0	343.200,00
Brita	1764,0	185.255,28
	Total	528.455,28

Sizing with Drainage Geocomposite

As already demonstrated in item 2 of this work, geosynthetic design is only about verifications, in order to ascertain if the pre-chosen product will perform well when used under specific design conditions. The geocomposite used in the checks was MacCaferri's MacDrain® 2R5 20.2. In order for this product to be able to be used as a drainage layer, it must meet the retention criterion (TAA), permeability criterion and the clogging criterion.

As for the retention criterion, it requires that the opening of the geotextile be small enough to prevent the migration of fine soil particles to the drain. Thus, and based on the retention criteria of Christopher and Holtz (1985), Carroll will be used (1983), we have Equation 5.

$$TAA < D85 * B \qquad (5)$$

Where:

TAA: Apparent aperture size (mm);

D85: Particle diameter that corresponds to 85% of the soil to be screened.

B: Coefficient ranging from 1 to 3.

For granular soils, with less than 50% passing through sieve #200, B is determined as a function of the coefficient of uniformity Cu = D60/D10, as shown in Equation 6.

$$Cu \leq 2 \text{ and } Cu \geq 8 \; B=1 \qquad (6)$$
$$1 < Cu \leq 4 \; B=0.5 * Cu$$
$$4 < Cu \leq 8 \; B=8/ Cu$$

In the case of sandy and poorly graded soils, B is between 1.5 and 2. And for fine soils with more than 50% through the #200 screen, B depends on the type of geotextile, and for non-woven geotextiles we have Equation 7.

$$B= 1.8 \; TAA \leq 1.8 * D85 \qquad (7)$$

The permeability criterion only requires that the permeability of the geosynthetic (Kg) is higher than that of the soil in which it will be installed (Ks), in the case of a laminar flow with a percentage of fines of up to 50%. For critical flow Kg should be 10 times greater than Ks.

Finally, in order for the product to meet the clogging criterion – that is, clogging of the geocomposite opening over time, it must have a porosity greater than 50%.

After verifying whether the product meets the above-mentioned criteria, the required permittivity and flow rate must be verified with the admissible through equations 2 and 3 mentioned in item 2 of this work.

Subsequently, the verifications and considering the dimensions of 40 m wide, for a dam with 200 m in length, 8000 m² of the drainage geocomposite would be required. Knowing that the average value of this geosynthetics in the market is R$ 40.00 reais per m², the cost of the product for the drainage system with drainage geocomposite would be R$ 320,000.00 reais.

CONCLUSION

As demonstrated in the course of the work, it is observed that the use of drainage geocomposite as an internal drainage system of dams is an efficient, simple and cost-effective method. When compared to the conventional system, geosynthetics have several advantages in terms of cost and execution. The executive procedure with geocomposite is simple and does not require as much special care as granular materials. As seen, for the conventional system to be efficient, the properties of granular materials cannot be altered, in this sense, it is of paramount importance that it is not contaminated, segregated and stored incorrectly. While the only care required with geosynthetics is with sharp materials that can puncture or tear the product.

As for the cost, the simulation shows that for the same dam and the same flow, the solution with drainage geocomposite was 35% cheaper – only in terms of material cost – than the one with granular material. It should be noted that the thickness and volume of granular material required is directly proportional to the design flow, thus, very high flow rates are required Much greater thicknesses of granular material, a fact that makes the work considerably more expensive. It should also be noted that this saving is even greater when considering labor costs and execution time. Since the solution with drainage geocomposite does not require specialized labor and its execution is faster compared to the solution with granular material.

Another important point is transportation, geosynthetics are available in rolls, do not require specific vehicles and, depending on demand, are available for immediate delivery. On the other hand, granular materials need to be transported in dump trucks and are taken from quarries, quarries, close to the construction site. However, these locations are not always close to each other or do not have material that meets the design specifications.

It is concluded that, in general, geosynthetics have advantages over all the criteria analyzed in this work. However, they are still little used, due to the insecurity of professionals in using an alternative method with a short history of use.

Finally, it is important to emphasize that the results presented in this study apply to the particular simulated situation. For conditions other than those described here, they must be evaluated on a case-by-case basis and the verifications regarding the efficiency of the geocomposite must be reevaluated, adapting to the new conditions.

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