World Academy of Science, Engineering and Technology
International Journal of Geotechnical and Geological Engineering
Vol:18, No:11, 2024

Open Science Index, Geotechnical and Geological Engineering Vol:18, No:11, 2024 publications.waset.org/10013890.pdf

Clogging Reduction Design Factor for Geosynthetics Used in Sustainable Urban Drainage Systems and Roads

Jaime Carpio-García, Elena Blanco-Fernández, Javier González-Fernández, Daniel Castro-Fresno

Abstract**—**Sustainable urban drainage systems (SUDS) are more often used in order to prevent floods, water treatment, fight against pollution, urban heat island effect, and global warming in applications like green roofs, permeable pavements, and others. Furthermore, geosynthetics are also worldwide used as a part of drainage systems in road construction. Geotextiles are an essential part of both, and one of the main geotextile properties in those applications is permeability, whose behavior is not well established along its service life. In this paper, clogging reduction design factors for an estimated service life of 25 years are experimentally obtained for five different geotextiles used in SUDS and roads combined with two different soils and with two pollutants, motor oil, and lime, in order to evaluate chemical clogging, too. The effect of characteristic opening size and other characteristics of the geosynthetics are also discussed in order to give civil engineers, together with the clogging reduction factors, a better long-time design of geotextiles used in their SUDS and roads.

Keywords**—**Geotextiles, drainage, clogging, reduction factor.

I. INTRODUCTION AND BACKGROUND

SUDS, like permeable pavements, green roofs, bioswales, wetlands, detention basins, and others, are being increasingly more often used in order to mitigate large volumes of runoff water from storms and to treat this water; that is, to approximate the urban water cycle to the natural water cycle, in order to minimize the impact of urban surfaces on the quality and the water path in Nature, as explained by [1].

Besides, the use of geosynthetics in roads drainage system and, more recently, in permeable roads, is a quite common practice to improve the water management, the security and durability of any highway, as pointed by [2]-[4]. Nevertheless, sometimes contractors or even project managers decide not to place them on site in order to save costs of the project and because they consider them useless and even harmful when they clog; e.g., when they are used as filters to separate different types of backfilling.

Geotextiles have become an essential part of any SUDS design or roads. They separate different soils in order to prevent their mixing, they redirect water to carry it to non-dangerous places or they collaborate to reinforce soils wherever it is needed. A better comprehension of geotextiles behavior implies a better SUDS or roads design and, therefore, a better performance.

Due to the importance of water transport and treatment in SUDS and roads, the system permeability is an essential feature, especially for geotextiles or products related with them. A minimum permeability should be maintained during all SUDS, road and geotextile service life, usually 25 years, to guarantee a correct drainage.

When engineers have to design a geotextile for SUDS or roads, they calculate the minimum permeability that they need for their system. Afterwards, they choose an adequate geotextile and take its permeability parameter, calculated in lab. Then they apply to that value the "reduction factors" in order to study if at the final of its service life the permeability will be higher than the necessary minimum, as explained in [5]. In this case, the main reduction factor to apply to geosynthetics in SUDS is due to clogging, which may be mechanical, chemical or biological, regardless other reduction or even security factors.

However, those reduction factors are not well established, especially for SUDS. They were usually calculated for wall drainage, erosion control filters, and tunnel drainage. Values for roadside drainages (usually ditches at the side of non-permeable pavements) are given but, as other clogging reduction factors, they are very general, unspecific and, perhaps, outdated. The best-known example is the tables in [5]. Those tables, which are the main reference for thousands of designers, have been barely revised since 1998. They are still a great starting point, but they need to be amplified and updated to consider the most recent geotextile products used not only in roadside drainage, but in recent SUDS applications.

A bad clogging estimation during the geotextile service life can be the origin of failures or bad performances in civil works, as those studied in [6]. There are some research projects which have tried to solve this problem. Some of them try to develop models to estimate clogging; for example, [7] for reinforced soils or [8] for tunnel drainage; others indicate good design criteria based on the characteristic opening size of the geotextile, like [9]. Additional interesting works are those who study geotextile clogging in very particular applications, although not SUDS, like [10] and [11].

All of them are useful approaches and more effort is needed in that way, using lab methods which simulate real conditions.

J. Carpio-García is with GITECO, University of Cantabria, Santander (Cantabria), 39005 Spain (corresponding author, phone: +34 942 20 15 65; fax: +34 942 20 17 03; e-mail: jaime.carpio@unican.es).

E. Blanco-Fernández, J. González-Fernández, and D. Castro Fresno are with GITECO, University of Cantabria, Santander (Cantabria), 39005 Spain (e-mail: elena.blanco@unican.es, javier.glez.fdez@hotmail.com, castrod@unican.es).

However, for many little projects simple reduction factors are more useful that models that could be complex or not always applicable to all the situations, and the local approaches are usually too specific. Updated clogging reduction factors for a wide variety of situations could help efficiently to engineers to design geotextiles for SUDS and roads.

Reference [12] established a method to calculate reduction factor due to installation damage for geotextiles used in permeable pavements. In that thesis, author worked with the different configurations of a geotextile in permeable pavements shown in Fig. 1, which are remarkably similar to those used in highway filter drains [13].

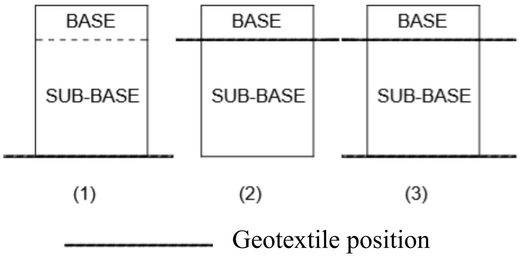


Fig. 1 Possible geotextile positions in a permeable pavement; extracted from [12]

The following reduction factors for non-woven geotextiles due to damage during installation were obtained from those configurations:

- When the base material is drainage aggregates with up to 15% of fines under 2 mm: 1.3 to 2.
- When the base material is drainage aggregates without fines under 2 mm: 1.1 to 1.3.

The obtained reduction factors were similar independently from the position of the geotextile in between different layers of the pavement section. However, the characteristic opening size of the considered geotextile is an important factor, because the maximum values of the shown ranges were always obtained with the geotextile with smaller opening size.

Considering this initial point, the present paper continues calculating reduction factors due to clogging for SUDS and roads. Long term mechanical and chemical clogging reduction factors are obtained for five different geotextiles usually used in SUDS, especially in permeable pavements and road drainage, but also in green roofs and others. Two kinds of soils are used to get those factors and two common urban pollutants are also included in the experimental programme to obtain the chemical clogging reduction factors. Possible synergies or interferences between soils and pollutants are also studied. Biological clogging will not be considered.

II. METHODOLOGY, EXPERIMENTAL EQUIPMENT AND MATERIALS

A. Methodology

There are not completely specific test standards which indicate how to calculate clogging of geotextiles. Some ASTM standards study filtration problems of geosynthetics. The main ones are these:

- ASTM D5141 [14] and ASTM D7351 [15] standards, which estimate the filtration capacity and efficiency of geotextiles, not specifically clogging. Besides, they are in-situ tests elaborated for checking each specific combination of soil and geosynthetic in each civil work, not laboratory tests which allow to elaborate models or general design parameters.
- ASTM D5101 [16] and ASTM D5567 [17] standards, which evaluate the compatibility of a soil and a geotextile, considering clogging but, at the same time, other phenomena as particle loss, large differences in water gradient, blinding, etc. They are laboratory tests but, as it is even indicated in the standards, they are not useful to provide job specifications or to help in manufacturers' certifications, because they also are made for evaluating specific combinations of soils and geotextiles for each project.

There are more examples of laboratory methodologies and experimental equipments to study clogging. The main ones are:

- Modifications of Sansone and Koerner's Fine Filtration Test, used in [7] and [18].
- Different kinds of permeameters or soil cells which modify the one in ASTM D5101 standard, for example the one in [19] and the improved one in [10], than allows cyclic flow in two directions.

The methodology used in this paper consisted of introducing different geotextile materials in a permeameter which could produce clogging when different soils and pollutants were added. After that, the water permeability characteristics normal to the plane, without load, of those clogged geotextiles were measured and compared with its as-received permeability values. This methodology allows to easily obtain clogging reduction factors which are useful for engineers as general values in their designs and, overall, it is an easily reproducible method for any researcher who wants to correct or to continue this work in other conditions or with other materials.

B. Experimental Equipment

Clogging of geotextiles was studied using two laboratory apparatus. Firstly, geotextile samples were clogged using the infiltrómetro cántabro fijo (ICF) permeameter. Afterwards, permeability normal to the plane of each geotextile was measured after the clogging phase according to EN-ISO 11058:2020. Reduction factors were obtained dividing the result of the permeability test of samples before clogging between results after clogging.

The ICF, a permeameter especially designed for SUDS (please consult [4], [20] and [21]), was used to provoke clogging in geotextiles. It can be examined in the photographs of Fig. 2, where its parts are indicated. As all infiltrometers, it was initially thought to calculate the water infiltration capacity and water treatment of different SUDS, especially permeable pavements but, from another point of view, the same apparatus can be used for measuring clogging capacity. Its section size was 30 x 30 cm.

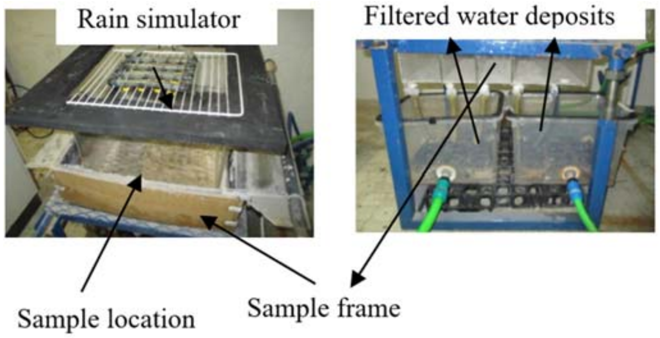


Fig. 2 Scheme of the ICF used in this experimental research

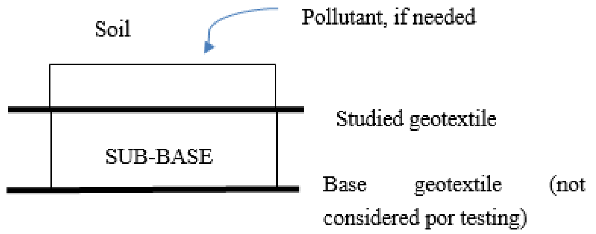


Fig. 3 Scheme of permeable system to estimate clogging

Fig. 4 Experimental device for permeability normal to the plane test according to [22]

Fig. 3 shows the scheme of the sample structure, which imitates a permeable surface typically used in SUDS and in roads, eliminating the upper permeable part (permeable blocks, permeable asphalt mix, porous concrete, aggregates, organic earth, etc.), just enabling the geosynthetic and a soil layer with or without pollutants on it, what simplifies the research. Subbase was formed by a 10-12 cm layer of non-washed lime aggregates with a diameter up to 24 mm. Sub-base aggregates and base geotextile have similar or bigger permeability than the studied geotextile. Soil is the element with less permeability.

The U-shaped equipment shown in Fig. 4 was used in order to measure permeability according to EN-ISO 11058:2010 standard [22]. The 55 mm diameter specimens were placed in the center of the left part of the U, where a relative pressure gauge is placed in order to measure the water height on the specimen during time, without removing the soil particles in the specimen.

C. Pollutants and Soils Used for Clogging

Two quite common urban pollutants have been considered: lime filler and HLP 46 motor oil. There are a large variety of motor oils, but the HLP 46 one was chosen because it is less viscous and it is more possible for it to go through the soil during the rain events, thus contact with the geotextile is helped.

Five geotextile materials were selected for the experimental program, including thermo-welded geotextiles, woven geotextiles and needle-punched non-woven geotextiles with different thicknesses. All of them are usually used for different SUDS applications and in road drainage systems, too. Even nearly all geotextiles used for SUDS are similar to one of them. Thicker or heavier geotextiles were not selected because they are not used for SUDS. Their main characteristics are shown in Table I and their photographs are shown in Figs. 5 (a)-(e).

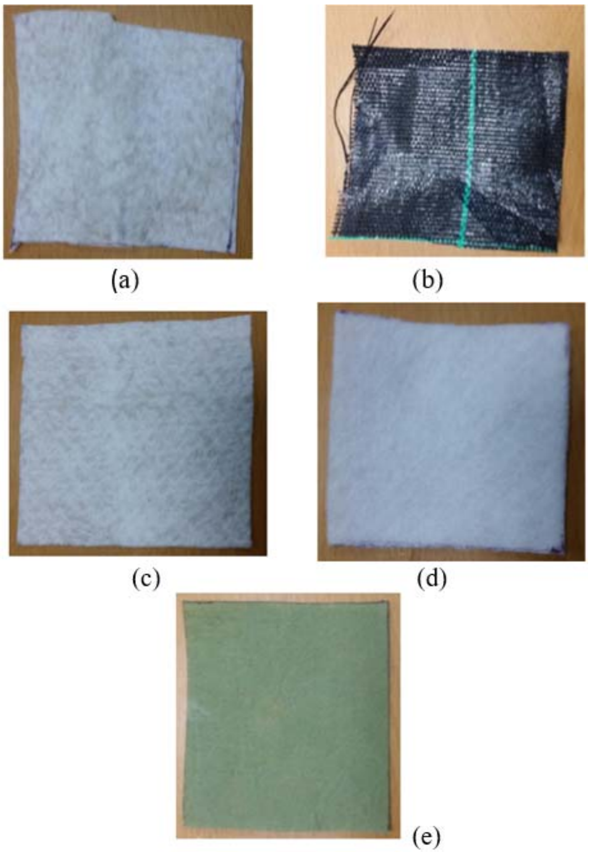


Fig. 5 Photographs of the materials which are described in Table I: (a) Material 1: 100 g/m^2 PP non-woven; (b) Material 2: PP 100 g/m^2 woven; (c) Material 3: 200 g/m^2 PP non-woven; (d) Material 4: 300 g/m^2 PP non-woven; Material 5: 100 g/m^2 PP-PE non-woven; (e) Material 5: 100 g/m^2 PP-PE non-woven GTX

The geotextile technical sheets indicate their properties with very low precision, so their physical and mechanical characterization was made prior to the experimental program. The obtained results are shown in Table II. The most important property is characteristic opening size, O_{95}. References [9], [12], [19] and [23] state that this property and its relation with soil granulometry play an important role in clogging mechanism.

Concerning soils, two were selected for this experimental program: a sandy lime with very low fine proportion (20% under 1 mm and 0% under 0.25 mm), and a clay soil with high fine proportion (50 % under 0.25 mm). The first is considered as "selected" by Spanish regulation PG-3 for embankment and soils in civil works [24], or SW according to USCS [25], and the second is considered as "tolerable" by [24] or CL according to [25]. The selected soil was no plastic. The tolerable soil had liquid limit LL = 30.3, a plastic limit LP = 19.45 and a plasticity index IP = 10.85, according to EN ISO 17892-12 standard [26].

TABLE I
SUMMARY OF THE MATERIALS USED IN THE EXPERIMENTAL PROGRAM

Nr	Description	Trademark	Model	Manufacturing technique
1	100 g/m^2 PP white GTX	Intermas	Techdrain GTG 512 (upper GTX)	Nonwoven, needle-punched+heat laminated to the geonet
2	100 g/m^2 PP black GTX	SICOR	Groundcover weaving	Woven
3	200 g/m^2 PP white GTX	Edil floor	Geodrain A5	Nonwoven, needle-punched
4	300 g/m^2 PP white GTX	Edil floor	Geodrain PPST 300 P	Nonwoven, needle-punched
5	100 g/m^2 green GTX (70% PP-30%PE)	Terram	INBITEX	Nonwoven, thermo-welded filaments

PP = polypropylene; PE = polyethylene; GTX: geotextile

TABLE II
MECHANICAL AND PHYSICAL LABORATORY TEST RESULTS ON THE SELECTED MATERIALS

Mat. Nº	Mass per unit area (g/m^2)	MD Tensile strength (kN/m)	MD Tensile strain (%)	CD Tensile strength (kN/m)	CD Tensile strain (%)	Thickness (*) (mm)	Characteristic opening size (µm)
1	144	15.95	58.78	14.21	46.75	0.872	107
2	101	22.37	14.06	16.76	11.39	0.239	224
3	215	7.74	61.17	9.70	40.9	1.181	70
4	279	10.69	25.60	7.80	23.07	2.860	65
5	145	21.67	64.59	25.99	73.74	0.711	145

MD: machine direction; CD: cross direction; (*) At 2 kPa of normal pressure

III. EXPERIMENTAL PROGRAM AND RESULTS

The test program consisted on six runoff events to provoke clogging of geotextile samples. Each one simulates the water quantity that is expected to fall in Santander, a coast city in the north of Spain, for 25 years, a total 28000 mm, or 2520 L for a 30x30 cm section. Water flow was regulated in each case in order not to overcome the permeability of the system and not to wash off the pollutant or soil layer from the sample.

The six events are summarized in Table III. Events 1 and 2 were designed to determine clogging effect considering only each type of soil. Events 5 and 6 help study the chemical clogging due to each pollutant, and events 3 and 4 combine both pollutants together and each soil. When pollutants were used, 88 g of oil, which is aprox. 15% more than the maximum estimated concentration in an urban road for 28 m of water precipitation during 25 years, according to [27] and 1 kg of lime filler (the enough quantity for covering all the surface of the sample) were used by event.

TABLE III
FLOOD LAB EVENTS FOR EACH GEOSYNTHETIC

Flood event	Description	Soil
1	Only water	Selected (*)
2	Only water	Tolerable (**)
3	Water+lime filler+oil	Selected (*)
4	Water+lime filler+oil	Tolerable (**)
5	Water+lime filler	None
6	Water+oil	None

(*) According to Art. 330 of Spanish regulation PG-[24], SW according to [25].
(**) According to the Spanish regulation [24], CL according to [25].

Blinding was detected in nearly all samples in contact with the "tolerable" soil, which was very clayey, independently from the opening size of the tested geotextile. In those cases, water flow was reduced in order to guarantee that all the water volume went through the geotextile. When blinded soil was completely impermeable, the clogging phase was stopped, what occurred approximately with a water volume of 1000L-1250 L. After drying, it was checked that clay layer on the geotextile was not bonded to it and that samples had been filled with soil and/or pollutants, so the test was considered as correct, because blinding was produced at the same time as clogging (they are not separable phenomena for these test conditions), and no more clogging could be produced in the mentioned test conditions, quite close to the actual conditions.

After each runoff event, a permeability test normal to the plane according to EN-ISO 11058:2010 standard [22] was performed in the experimental device shown in Fig. 4, plus the same test on each geotextile in as-received conditions, so a total of: 6 clogging events x 5 geotextiles + 5 as-received geotextiles = 35 permeability tests

Five specimens were extracted from each clogged sample and as-received sample, so a total of 175 specimens were tested.

Each clogged sample from the permeameter was dried at room temperature prior to the permeability test. All permeability tests were performed using the falling head method, in order not to wash off pollutants or particle soils. The obtained result, according to the standard, was the velocity index at 20 ºC and at 50 mm of head loss, V_{H50} at 20ºC, in mm/s.

Table IV summarizes the results for the 35 tests, with their uncertainties. In this table the clogging reduction factor, CRF, in a specific condition of material and flood event, was defined as usually, according to (1):

$$\text{CRF} = \frac{\text{Permeability before clogging}}{\text{Permeability after clogging}} \qquad (1)$$

The $\text{CRF}_{\text{design}}$ parameter is the sum of the obtained mean CRF for the geotextile, soil and pollutant (if it exists) plus its uncertainty, in order to work on the side of safety.

The uncertainty of each mean permeability value (mean calculated from 5 specimens) was calculated according to [28], and CRF uncertainty, U_{CRF}, was calculated applying (2):

$$U_{CRF} = CRF \cdot \sqrt{W_{Perm-before}{}^{2} + W_{Perm-after}{}^{2}} \qquad (2)$$

where $W_{\text{Perm-before}}$: relative expanded uncertainty of the permeability before clogging, according to [28]; $W_{\text{Perm-after}}$: relative expanded uncertainty of the permeability after clogging, according to [28].

TABLE IV
CRF FOR DIFFERENT GEOTEXTILES, SOILS AND POLLUTANTS

Material	Soil	Pollutant	CRF	$\text{CRF}_{\text{DESIGN}}$
1	Sandy	None	1.61 ± 0.48	2.1
		Lime filler+oil	2.41 ± 0.75	3.2
	Clayey	None	1.63 ± 0.60	2.2
		Lime filler+oil	1.25 ± 0.40	1.7
	None	Lime filler	0.93 ± 0.28	1.2
		Oil	1.17 ± 0.45	1.6
2	Sandy	None	0.72 ± 0.08	0.8
		Lime filler+oil	1.62 ± 0.16	1.8
	Clayey	None	0.73 ± 0.07	0.8
		Lime filler+oil	0.95 ± 0.11	1.1
	None	Lime filler	0.72 ± 0.08	0.8
		Oil	0.99 ± 0.09	1.1
3	Sandy	None	2.43 ± 0.66	3.1
		Lime filler+oil	4.06 ± 0.98	5.0
	Clayey	None	3.25 ± 0.57	3.8
		Lime filler+oil	1.83 ± 0.55	2.4
	None	Lime filler	2.71 ± 0.50	3.2
		Oil	1.15 ± 0.20	1.4
4	Sandy	None	4.97 ± 0.61	5.6
		Lime filler+oil	6.29 ± 0.70	7.0
	Clayey	None	2.38 ± 0.33	2.7
		Lime filler+oil	2.18 ± 0.22	2.4
	None	Lime filler	4.97 ± 0.53	5.5
		Oil	1.45 ± 0.17	1.6
5	Sandy	None	2.31 ± 0.36	2.7
		Lime filler+oil	5.51 ± 1.06	6.6
	Clayey	None	1.30 ± 0.34	1.6
		Lime filler+oil	1.03 ± 0.20	1.2
	None	Lime filler	0.89 ± 0.16	1.1
		Oil	0.96 ± 0.16	1.1

IV. DISCUSSION

Table IV gives the CRF due to clogging in permeable pavements including the uncertainty of the values. These values need more research to consolidate the obtained parameters and for calculating them in more actual situations and with other materials, although the selected geotextiles in this paper are quite representatives of those used in SUDS and roads for filtering and drainage applications. Nevertheless, these first basic data are useful for engineers which cannot perform in-situ clogging test for their civil works due to costs, time or other reasons.

An example of use of Table IV is the following one: an engineer desires to evaluate the long-time clogging behavior of a 200 g/m² non-woven PP geotextile for a green roof. He/she knows the initial permeability value of the product, P_1, and he/she knows that the soil on that geotextile will be an organic soil with a granulometry and plastic behavior that make it similar to our “tolerable” soil. There will be no appreciable pollutant quantity. The mechanical CRF range to apply in that case would be 3.25 ± 0.57, corresponding to a non-woven geotextile of 200 g/m², clayey soil without pollutants. For design purposes, it might be more suitable instead of taking the average value, 3.25, the design value, 3.8, which is conservative. So, the estimated permeability value P_2 of that geosynthetic after 25 years in the green roof would be expressed in (3):

$$P_2 = P_1/3.8 \qquad (3)$$

Some points about Table IV should be highlighted:

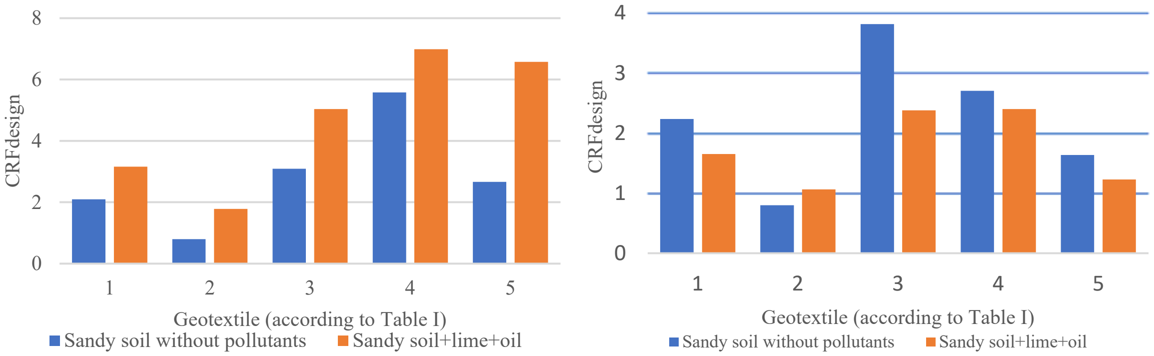
1. Reduction factors below 1 are obtained in many cases, especially for woven geotextiles: any manipulation during installation (regardless any damage during installation, already studied by [12]) and the effect of water pressure and oil or solid particles opens canals in the geotextile. This is an important point because this possibility (CRF under 1) has not been found in the consulted references for SUDS.
2. With sandy soils, soil and pollutants create synergy and promote an increased clogging effect, as shown in Fig. 6 (a). Nevertheless, the combined effect is not equivalent to multiply CRFs due to soil and due to pollutant separately, as indicated in [5]. This point should be reconsidered in future researches and geosynthetic manuals.

Besides, Fig. 6 (b) demonstrates that in clayey soils, in nearly all the case studies, the combination of pollutants and soil decreases clogging. That is supposed to be caused by the oil, which can penetrate and impregnate geotextile fibers when sandy soils without fines are used. In those cases, that oil can stuck soil particles to the geotextile, promoting clogging. But the same oil, even such a fluid oil as HP46, remains stuck to the fines when clayey soils are used, producing a lump that makes more difficult for these oils or filler to penetrate the geotextile. In this case, blinding is the promoted phenomenon, not clogging.

The relation between the characteristic opening size of the geotextile and the particle size of the soil is confirmed: CRF increases if opening size decreases for similar geotextiles, as shown in Table IV and Figs. 7 (a)-(c). Fig. 7 corresponds to a graphic CRF-geotextile property for materials 1, 3 and 4, all of them non-woven needle-punched PP geotextiles with increasing mass per unit area, increasing thickness and decreasing characteristic opening size, considering all the flood events. Data were extracted from Table IV. References [9], [12], [19] and [23], among others, pointed that and it has been confirmed in this research, but there is not enough data to give exact correlations or recommendations at this point, beyond Holtz recommendation, expressed in (4), about the minimum criterium for geotextile selecting in order to avoid clogging:

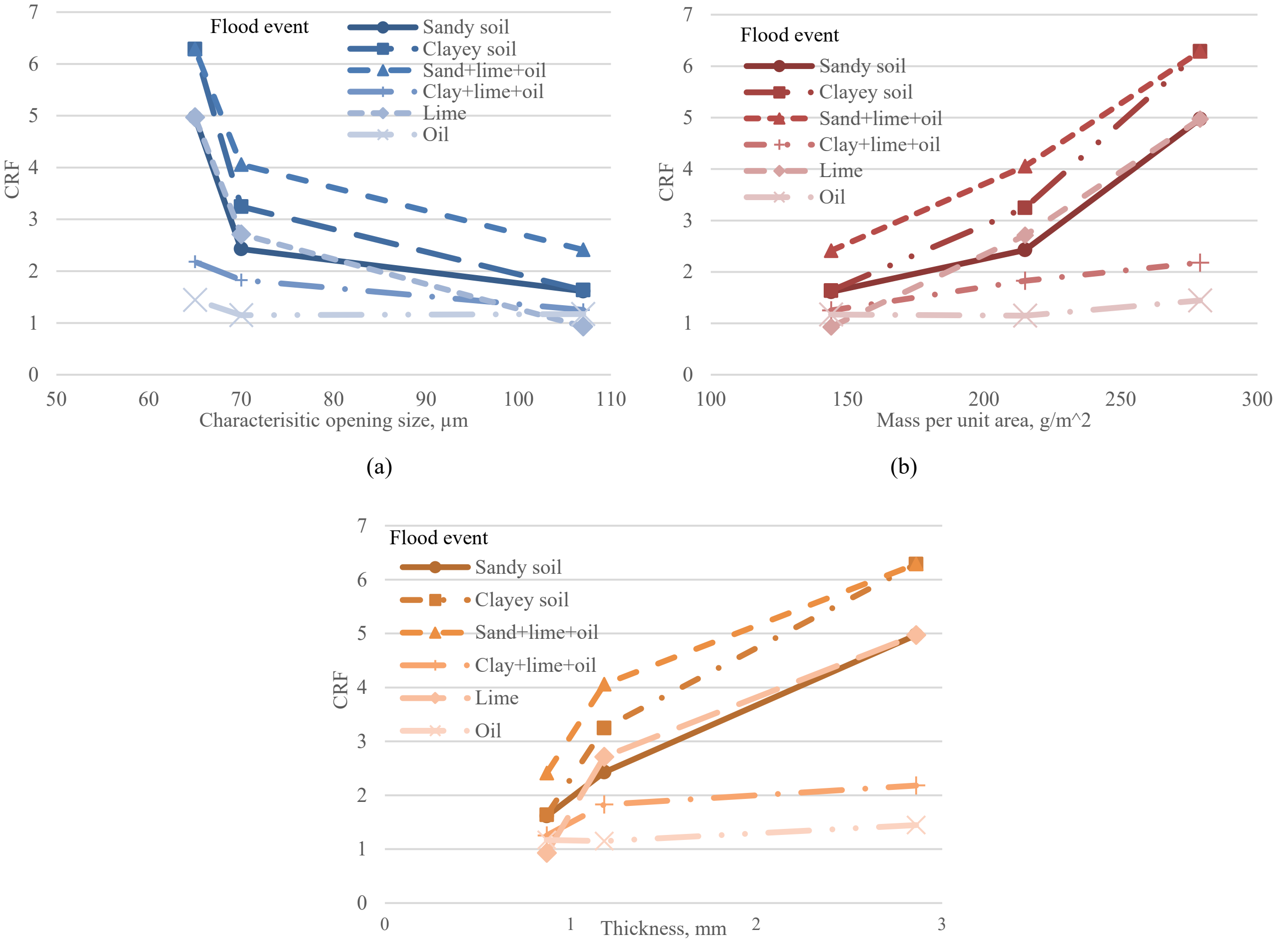
$$O_{95} \geq 3 \cdot D_{15} \qquad (4)$$

If engineers do not know the characteristic opening size, which is not frequent nowadays, but either impossible, increasing thickness or mass per unit area in similar geotextiles from the same company are related with a slight reduction of characteristic opening size and a larger CRF, as demonstrated in Figs. 7 (b) and (c) and Tables II and IV.



(a) (b)

Fig. 6 Pollutant effect on CRF design for: (a) Sandy soil; (b) clayey soil



(a) (b)

(c)

Fig. 7 CRF behavior vs changes in different characteristics of PP non-woven geotextiles: (a) opening size; (b) mass per unit area; (c) thickness

Thermo-welded geotextiles perform worse than needle-punched geotextiles when sandy soils are used, especially when pollutants are present. Thermo-welded geotextiles, like those used in SUDS, are capable to retain a water layer on them because they can increase the water surface tension on them, which promotes the developing of a biofilm that can purify water. Nevertheless, this property could influence on the behavior versus clogging of this geotextile, compared with those which are only needle-punched, even if the most similar needle-punched sample (material 1) has less characteristic opening-size than the thermo-welded one (material 5), as can be consulted in Tables II and IV.

V. CONCLUSION

A table with updated clogging reductions factors of geotextiles used in SUDS and roads has been obtained (Table IV). The results are quite precise and sum up a wide range of geotextile materials and design situations.

More work is needed in order to consolidate and get more valid CRF, but the information in this paper is already useful when little data about geotextiles are available in SUDS or road drainage systems design and no in-situ tests are also possible, which is very frequent because many SUDS projects are still few and their budgets do not allow to pay expensive studies or in-situ tests, even in such critical materials for these applications like geosynthetics.

Some important facts pointed in other bibliography have been confirmed in this paper, like the influence of the geotextile characteristic opening-size and soil granulometry on clogging. Besides, other factors that influence the clogging behavior have been found, like production technics of the geotextiles, synergies or interferences between soils and pollutants. Finally, CRF below 1 due to any manipulation or the effect of water, soils and pollutants on the studied materials have also been discovered.

ACKNOWLEDGMENT

Authors want to thank Jorge Rodríguez Hernández, whose expertise and advice on SUDS and the ICF were a guide in this research. They also want to thank the School of Civil Engineering of the University of Cantabria, whose student research program allowed Javier González to participate in this research. And, finally, authors thank the Geosynthetics Laboratory of the University of Cantabria (LAGUC), for allowing the use of its equipment for performing all the mechanical and permeability tests on the geotextiles.

REFERENCES

[1] J. Rodríguez-Bayón, D. Castro-Fresno, J. Rodríguez-Hernández, F. Ballester Muñoz, “Sistemas urbanos de drenaje sostenible (SUDS),” Interciencia, vol. 30-5, pp. 255-260, 2005

[2] E. Gómez-Ullate, J.R. Bayón, S. Coupe, D. Castro-Fresno, “Performance of pervious pavement parking bays storing rainwater in the north of Spain,” *Water Science and Technology*, vol. 62-3. pp. 615-621, 2010.

[3] E. Gómez-Ullate, E. Castillo-López, D. Castro-Fresno, J. Rodríguez-Bayón, “Analysis and contrast of different pervious pavements for management of storm-water in a parking area in northern Spain,” *Water Resources Management*, vol. 25, pp. 1525-1535, 2011.

[4] L.A. Sañudo-Fontaneda, S.M. Charlesworth, D. Castro-Fresno, V.C. Andrés-Valeri, J. Rodríguez-Hernández, “Water quality and quantity assessment of pervious pavements performance in experimental car park areas,” *Water Science and Technology*, vol. 69-7, pp. 1526-1533, 2014.

[5] R.M., Koerner, 2012. *Designing with geosynthetics*, 6th Edition, Xlibris Press. Indiana, USA, 2012, vol. I, ch. 2.

[6] R.M. Koerner, G.R. Koerner, “Lessons learned from geotextile filter failures under challenging field conditions,” *Geotextiles and Geomembranes*, vol. 43, pp. 272-281, 2015.

[7] Y.H. Faure, A. Baudoin, P. Pierson, O. Plé, “A contribution for predicting geotextile clogging during filtration of suspended solids,” *Geotextextiles and Geomembranes*, vol. 24, pp. 11-20, 2006.

[8] K.H., Kim, N.H. Park, J.H. Shin, “Modelling of hydraulic deterioration of geotextile filter in tunnel drainage system,” *Geotextiles and Geomembranes*, vol. 48, pp. 210-219, 2020.

[9] R.D. Holtz, B.R. Christopher, R.R. Berg, “Sediment control”, in *Geosynthetic Engineering,* BiTech Publishers, Ltd. Richmond, B.C., Canada, 1997.

[10] A. Miszkowska, S. Lenart, E. Koda, “Changes of permeability of nonwoven geotextiles due to clogging and cyclic. Water flow in laboratory conditions,” *Water*, vol. 9, pp 660-674, 2017.

[11] D.V. Raisinghani, B.V.S. Viswanadham, “Evaluation of permeability characteristics of a geosynthetic-reinforced soil through laboratory tests,” *Geotextiles and Geomembranes*, vol. 28, pp. 579-588, Aug. 2010.

[12] C. Casuso, *Estudio de zahorras y geotextiles para firmes permeables* (MsC thesis), University of Cantabria, Spain, 2015.

[13] L.A. Sañudo-Fontaneda, S.J. Coupe, S.M. Charleswoth, E.G. Rowlands, "Exploring the effects of geotextiles in the performance of highway filter drains” *Geotextiles and Geomembranes*, 46, pp. 559-565, 2018.

[14] “Standard test method for determining filtering and flow rate of the filtration component of a sediment retention device,” ASTM D5141-11(2018), ASTM International, Pennsylvania, 2018.

[15] “Standard test method for determination of Sediment Retention Device (SRD). Efectiveness in sheet flow applications,” ASTM D7351-19. ASTM International, Pennsylvania, 2019.

[16] “Standard test method for measuring the filtration compatibility of soil-geotextile systems,” ASTM D5101-12(2017), ASTM International, Pennsylvania, 2017.

[17] “Standard test method for Hydraulic Conductivity Ratio (HCR) testing of soil/geotextile systems,” ASTM D5567-94(2018), ASTM International, Pennsylvania, 2018.

[18] L.A. Sañudo-Fontaneda, S.M. Charlesworth, D. Castro-Fresno, V.C. Andrés-Valeri, J. Rodríguez-Hernández, “Water quality and quantity assessment of pervious pavements performance in experimental car park areas,” *Water Science and Technology*, vol. 69-7, pp. 1526-1533, 2014.

[19] Nishigata,T., Fannin, R.J., Vaid, P.V., 2000. Blinding and Clogging of a Nonwoven Geotextile. Soil.Found, 40-4, pp. 121-127.

[20] D. Castro-Fresno, V.C. Andrés-Valeri, A. Sañudo-Fontaneda, J. Rodríguez-Hernández, “Sustainable drainage practices in Spain, specially focused on pervious pavements”, *Water*, vol. 5-1, pp. 67-93, 2013.

[21] J. Rodríguez-Hernández, D. Castro-Fresno, A.H. Fernández-Barrera, A. Vega-Zamanillo, “Characterization of infiltration capacity of permeable pavements with porous asphalt surface using Cantabrian Fixed Infiltometer,” *Journal of Hydrology Engineering*, vol. 17-5, pp. 597-603, 2012.

[22] “Geotextiles and geotextile-related-products. Determination of water permeability characteristics normal to the plane, without load,” EN ISO 11058:2010, Brussels, 2010.

[23] E.M.. Palmeira, H.L. Trejos Galvis, “Opening size and filtration behaviour of nonwoven geotextiles under confined and partial clogging conditions,” *Geosynthetics International*, vol. 24-2, pp. 125-138, 2017.

[24] Ministry of Development (Ed.), “Terraplenes,” Pliego de prescripciones técnicas generales para obras de carreteras y puentes, PG-3, *Spanish Official Diary*, Madrid, Jan 3rd 2015, article 330.

[25] “Standard practice for classification of soils for engineering purposes (Unified Soil Classification System),” ASTM D2487-17, ASTM International, Pennsylvania, 2017.

[26] “Determinación del límite líquido y del límite plástico,” EN ISO 17892-12:2019, European Committee for Standardization (CEN), Brussels, 2019.

[27] A.H. Fernández-Barrera, *Desarrollo de un sistema de tratamiento del agua de escorrentía superficial procedente de aparcamientos impermeables usando flujo ascendente y geotextiles* (PhD. Thesis), University of Cantabria. Santander, Cantabria, Spain, 2010, p. 6.

[28] "Expressions of the uncertainty of measurements in calibration.," EA-4/02 M: 2013. European Cooperation for Accreditation, The Netherlands, 2013.

Open Science Index, Geotechnical and Geological Engineering Vol:18, No:11, 2024 publications.waset.org/10013890.pdf