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A study on soil-geotextile interaction using gradient ratio tests

Key words: nonwoven geotextile, soil, gradient ratio, clogging, permeability, filter

Introduction

Nonwoven geotextiles are made of randomly or directionally orientated fibres, filaments or other element, chemically and/or thermally and/or mechanically bonded (PN-EN ISO 10318). They have been widely used as filters in geoenvironmental and geotechnical works for over 50 years. This type of geosynthetics gathers special features that commonly lead to applications with faster execution and lower costs in comparison with traditional, granular filters. What is more, the use of nonwoven geotextiles can bring benefits for environment due to less emission of harmful gases to the atmosphere, less water consumption and energy and more environmentally friendly construction procedures, for instance (Heibaum, 2014; Koerner & Koerner, 2015; Yoo & Kim, 2016; Miszkowska & Koda, 2017; Palmeira & Trejos Galvis, 2018).

A geotextile performs the filtration function by limiting migration of soil particles across its plane, while allowing relatively unrestricted liquid flow through the filter over a projected service lifetime of the application under consideration. Filtration function also provides separation benefits (Giroud, 1981; Koda, Szymański & Wolski, 1989; Koerner, 2012). Figure 1 shows that a geotextile allows passage of water from a soil mass while preventing the uncontrolled migration of soil particles.

It is also worth mentioning that when a geotextile filter is placed adjacent to a base soil, between the natural soil structure and the structure of the geotextile arises a discontinuity, which allows some soil particles to migrate through the geotextile under the influence of seepage flows. It is important that a condition of equilibrium is established at the soil-geotextile interface as soon as possible

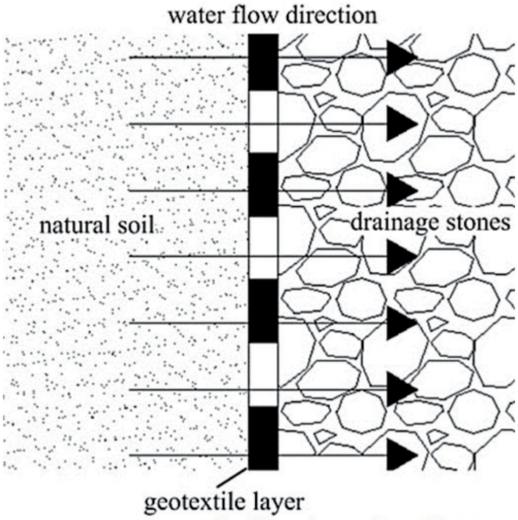

FIGURE 1. Geotextile filter (Wesolowski, Krzywosz & Brandyk, 2000)

to prevent soil particles being piped for an indefinite period through the geosynthetic. At equilibrium, three zones may be identified: the undisturbed soil, a soil layer, and a bridging layer (Wesolowski et al., 2000; Shukla, 2016; Miszkowska, Lenart & Koda, 2017).

The successful use of a synthetic filter is dependent on knowledge of the interaction between the base soil and the geotextile that is complex because of the large number of parameters involved. The essential properties to be determined are particle-size distribution and permeability of soil and water permeability normal to the plane, characteristic opening size, the number of constrictions in case of nonwoven (Giroud, 2010; Cazzuffi, Moraci, Mandaglio & Ielo, 2016).

What is more, nonwoven geotextiles are the first in contact with soil in filters applications, the design must be prepared to avoid the negative phenomenon causing a decrease of the permeability of the geotextile filter in time like clogging. Physical clogging is the accumulation of soil particles within the openings of a geotextile, thereby reducing its hydraulic conductivity (Fig. 2). Clogging can be also caused by chemical and/or biological processes (Stępień, Jędryszek & Koda, 2012; Koda, Miszkowska & Stępień, 2016; Miszkowska, Koda, Krzywosz, Król, & Boruc, 2016; Sabiri, Caylet, Montillet, Le Coq & Durkheim, 2017; Fatema & Bhatia, 2018).

One of the methods to evaluate compatibility between a granular base material and a geotextile filter is to use the gradient ratio (*GR*) test (Calhoun, 1972; Palmeira, Beirigo & Gardoni, 2000; Cazzuffi et al., 2016).

Fannin, Vaid, and Shi (1994) defined a modified gradient ratio using a port located 8 mm above the geotextile layer. Gardoni (2000) proposed a definition of *GR* using a port 3 mm above the geotextile filter to evaluate soil-geotextile interaction closer to the soil-filter interface. However, the definition of i_s in

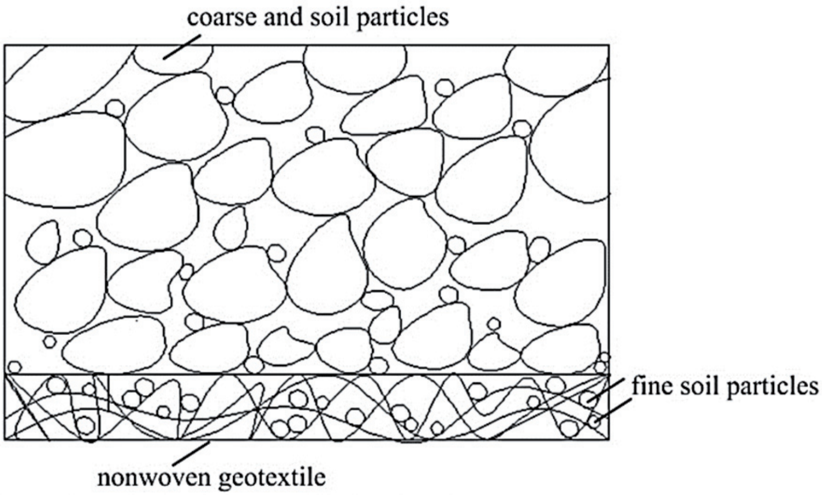

FIGURE 2. Physical clogging (Shukla, 2016)

both cases is the same as that proposed by ASTM.

To avoid clogging, gradient ratio should be less than 3 (Haliburton & Wood, 1982; Carroll, 1983). But according to ASTM D5101-12, a gradient ratio greater than 1.0 indicates system clogging or restriction at or near the surface of the geotextile.

The main aim of this study was to present the laboratory gradient ratio test results to evaluate soil-geotextile interaction. The following hypothesis can be proposed: gradient ratio, *GR* is changing with time and apart from gradient ratio also soil-gradient ratio, *SGR* should be determined to carry out a detailed analysis of soil-geotextile interactions.

Material and methods

In this study nonwoven geotextile, needle punched and made of continuous polypropylene fibres, was tested. The main properties of the geotextile are summarised in Table 1.

The soil used in gradient ratio test was classified as silty sand (siSa). According

TABLE 1. Properties of the geotextile tested (own and manufacturer studies)

Properties		Value
Mechanical	tensile strength – machine direction [$kN \cdot m^{-1}$]	25
	tensile strength – cross machine direction [$kN \cdot m^{-1}$]	25
	elongation at maximum load – machine direction [%]	50
	elongation at maximum load – cross machine direction [%]	60
	dynamic perforation resistance [mm]	12
Hydraulic	water permeability normal to the plane [$l \cdot m^{-2} \cdot s^{-1}$]	55
	characteristic opening size – O_{90} [μm]	65
Physical	thickness under 2 kPa [mm]	1.6
	weight [$g \cdot m^{-2}$]	300
	number of constrictions	22

to Kenney and Lau (1985) method the assessment of internal stability soils, the tested soil was internally unstable. The soil properties are shown in Table 2.

TABLE 2. Soil properties

Properties	Value
Soil particle d_{10} [mm]	0.012
Soil particle d_{15} [mm]	0.04
Soil particle d_{30} [mm]	0.12
Soil particle d_{50} [mm]	0.18
Soil particle d_{85} [mm]	0.27
Coefficient of curvature – C_c [-]	6
Coefficient of uniformity – C_U [-]	16.7
Coefficient of soil permeability – k_s [m·s^{-1}]	0.000079

d_n – the soil particle diameter that n% of all soil particles are finer by weight.

The gradient ratio was determined in the laboratory of Department of Geotechnical Engineering at Warsaw University of Life Sciences – SGGW using ASTM modified apparatus. Piezometers (6 and 7) were installed to obtain additional pressure measurements in the layer of soil situated close to nonwoven geotextile layer. Figure 3 shows a detailed schematic view of the device.

At the beginning of test, the soil was dried (in 105°C for 24 h) and sieved through a two-millimeter mesh. Then, the soil sample was placed on the nonwoven geotextile sample. After that, water was delivered into the apparatus from bottom to top for 24 h. In the next step of the test, flow direction was changed (Fig. 4). When the water flow reached a steady condition, the pressure of individual piezometer (Δh), temperature of the water flow (T), volume of the flow (V) and time of the flow (t) were measured for each of the hydraulic gradients at 1.0,

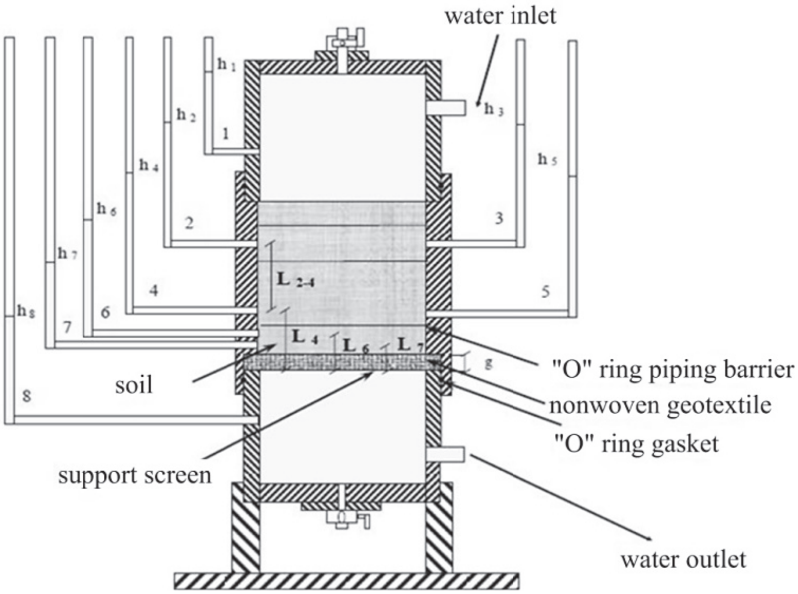

FIGURE 3. Scheme of gradient ratio test apparatus: g – nonwoven geotextile, L_n – distance between piezometer n-th and the bottom of geotextile, h_n – the piezometer reading for n-th piezometer (Wojtasik, 2008)

FIGURE 4. Front view of gradient ratio test device (photo by the author)

2.5, 5.0, 7.5 and 10.0 until the change of these parameters was not observed. The test was done in triplicate.

The following piezometer readings were taken in individual zones:

– for soil-geotextile:
    - zone 7–8 (geotextile and 4 mm layer of soil between piezometers 7 and 8),
    - zone 6–8 (geotextile and 8 mm layer of soil between piezometrs 6 and 8),
    - zone 4.5–8 (geotextile and 25 mm layer of soil between piezometers 4 and 5 to 8),
– for soil:
    - zone 6–7 (4 mm layer of soil within the distance from 4 to 8 mm above nonwoven geotextile between piezometers 6 and 7),
    - zone 4.5–6 (17 mm layer of soil within the distance from 8 to 25 mm above nonwoven geotextile between piezometers 4.5 and 6),
    - zone 2.3–4.5 (50 mm layer of soil within the distance from 25 to 75 mm above nonwoven geotextile between piezometers 2 and 3 as well as 4 and 5).

The value of the gradient ratio can be generally defined as (ASTM D-5101-12):

$$GR = \frac{i_{LG}}{i_s}$$

where:
GR – the gradient ratio,
i_{LG} – the hydraulic gradient across a soil thickness (L) and the geotextile,
i_s – the reference hydraulic gradient in the soil, measured in a region away from the geotextile (calculated for the segment of the soil specimen between 25 and 75 mm above the geotextile filter).

In the presented test, the gradient ratio in soil-geotextile system was calculated according the formula:

$$GR = \frac{\Delta h_{4.5-8}}{L_4} \frac{L_{2-4}}{\Delta h_{2.3-4.5}}$$

where:
GR – the gradient ratio,
$\Delta h_{4.5-8}$ – the difference manometer readings between average reading of 4 and 5 piezometers and 8 piezometer [mm],
L_4 – the distance between piezometer 4 and the bottom of geotextiles [mm],
L_{2-4} – the distance between piezometers 2 to 4 [mm],

$\Delta h_{2.3-4.5}$ – the distance in manometer readings between average reading of 2 and 3 piezometers and average reading of 4 and 5 piezometers [mm].

Also, the gradient ratio for the soil layers 17 mm above the geotextile was calculated from:

$$SGR_{17} = \frac{\Delta h_{4.5-6}}{L_{4-6}} \frac{L_{2-4}}{\Delta h_{2.3-4.5}}$$

where:

SGR_{17} – the gradient ratio for the soil layers 17 mm above the geotextile,

$\Delta h_{4.5-6}$ – the difference manometer readings between average reading of 4 and 5 piezometers and 6 piezometer [mm],

L_{4-6} – the distance between piezometers 4 to 6 [mm].

Results and discussion

Figure 5 shows the relationship between average values of gradient ratio, *GR* and soil-gradient ratio, SGR_{17} under hydraulic gradient from 1 to 10. The *GR* and SGR_{17} were calculated at the beginning of the tests (GR_s, $SGR_{17}s$; where: s – start) as well as when the water flow reached a steady condition (i.e. the changes in reading of piezometers were not observed – GR_f, SGR_{17f}; where: f – finish).

The obtained results show that the gradient ratio *GR* has increased from 0.75 to 0.9 under tested hydraulic gradient and soil-gradient ratio SGR_{17} has increased from 1.15 to 1.42 under tested hydraulic gradient. The gradient ratio and soil-gradient ratio have increased with time and with a higher hydraulic gradient because of clogging mechanism (Kutay & Aydilek, 2005; Wu, Hong, Yan & Chang, 2006; Fannin, Palmeira, Srikongsri, & Gardoni, 2008; Sabiri et al., 2017) but significant clogging occurred in the 17-mm soil layer situated in distance from 8 to 25 mm above nonwoven geotextile sample.

A review of the data shows that nonwoven geotextile tested with silty sand (siSa) would be considered to clogged based on criterion that sets of *GR* (*SGR*) of 1 as the limit (ASTM D5101-12),

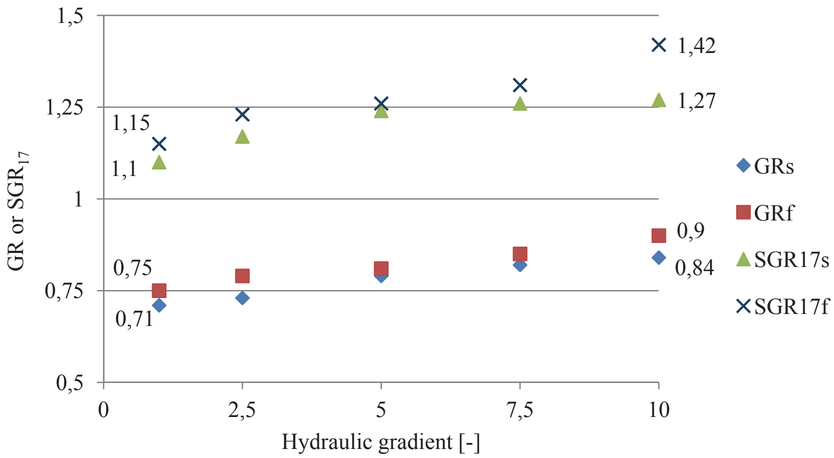

FIGURE 5. Relationship between *GR* or SGR_{17} and hydraulic gradien (own studies)

however would not be considered clogged when the US Army Corps of Engineers' limit of 3 is used (Haliburton & Wood, 1982). Fannin (2015) also confirmed that a *GR* value larger than 3 is an indication of excessive clogging. What is more, Fischer, Mare and Holtz (1999) showed that value of *GR* equal to 1 may not be representative because of analysis of a relatively small soil-geotextile contact zone in the gradient ratio apparatus. Nevertheless, the results confirm that not only gradient ratio, *GR* should be determined to evaluate and study soil-geotextile interaction but also soil-gradient ratio, *SGR*. In addition, Lafleur (2016) proposed a modified gradient ratio test which includes the measurement of the amount of particles passing through the geotextile and collected at the bottom of the permeameter, what can yield the complete portrait of the compatibility between a filter and a soil too.

Conclusions

The compatibility of a nonwoven geotextile and soil can be established by means of the gradient ratio test. Interpretation of the gradient ratio test is based on measurements of the head loss that occurs across the geotextile specimen and in the soil sample with imposed hydraulic gradient and with respect to time. The permeameter used in the tests was modified to better define the variation of head loss in the sample. The additional piezometers were installed closer to the top surface of the nonwoven geotextile. For that reason, it was possible to determine not only gradient ratio, *GR* (according to ASTM D5101-12) but also soil-gradient ratio, SGR_{17}.

The obtained results confirmed that gradient ratio as well as soil-gradient ratio increases with time due to physical clogging. However, based on filter design criteria, the tested nonwoven geotextile can be used as filter for internally unstable soil with fine content of 20%.

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Summary

A study on soil-geotextile interaction using gradient ratio tests. Nonwoven geotextile have been widely used for filtration. In this paper, the clogging potential for a soil-geotextile system were assessed using laboratory tests. An ASTM modified gradient ratio test device was used to determine gradient ratio as well as soil-gradient ratio. One type of nonwoven geotextile and soil were used to simulate the conditions in drainage system. The obtained results indicate that the gradient ratio and soil-gradient ratio increases with time because of clogging mechanism. However, the tested geotextile can be used as filter for soil with fine content of 20%.

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