Damage of geotextile due to impact of stones

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ABSTRACT: Impact tests of stones on a geotextile have been performed. The geotextile was mounted on a concrete cylinder of 0.8 m diameter filled with dry sand with a constant porosity. Tests were performed on woven and non-woven geotextiles and on composites. Drop tests were performed with concrete blocks of different shapes weighing all around 40 kg. The falling heights varied between 0.5 to 5.5 m.
Results show that the shape of the stone has a decisive influence. Furthermore, it appeared by PIV (Particle Image Velocimetry) that the loading on a woven is rather different from the loading on a non-woven. While a woven is loaded in the directions parallel to the yarns, the non-woven is loaded more uniformly.
A remarkable result was found for composite material consisting of a woven and a non-woven. The lowest geotextile was always the first one that was damaged. A possible explanation is presented in the paper.

Keywords: Geotextiles, damage during installation, impact stones, tests

1 INTRODUCTION

In several applications of geosynthetics, the geosynthetics are covered with gravel or even larger stones. Examples are a ballast bed underneath a railway track, slope protection, river and coastal engineering applications. It is known that the geosynthetic in such a situation is vulnerable to damage during installation. When large stones are dropped on the geosynthetic, it is possible that the geosynthetic is punctured or ruptured. This is especially dangerous for applications in river and coastal engineering. Here the geosynthetics is often used as a filter and puncturing or rupturing will allow transport of the fines from underneath the geosynthetic filter. This kind of damage is not unusual (CUR, 2004). To calculate when damage may occur a 2-D calculation method is presented in the Dutch guide line: Geotextiles underneath stone revetments (SBR-CUR, 2017). Furthermore, tests has been performed (Allen and Bathurst, 1994; Kendall, 2014) and BAW has developed a standardized method to test the impact resistance of geosynthetics (BAW, 1994). However, in most of this research only one impact stone or device was used. According to the calculation method described in the Dutch guideline, the angle between the stone surfaces is of importance.

This paper describes an experimental research programme to check the validity of the 2-D calculation method in a 3-D environment and to test the influence of the different types of geosynthetics. It describes the setup of the experiments and the results.

2 GEOMETRIC CONSIDERATIONS

2.1 *2-D theory*

The theory developed in SBR-CUR (2017) for stones with straight surfaces can be simplified to the following: Assume a stone penetrating in a geosynthetic placed on sand. In the worst case the geosynthetics is fixed by other stones. This means that the geotextile has to elongate. Again assuming a worst-case scenario

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the elongation has to come entirely from the geotextile underneath the falling stone. This was not found in our measurements were there was clearly elongation of the geotextile outside the impact zone, as will be shown later, but is the approach in SBR-CUR (2017). Following that approach, the strain in the geotextile can be calculated quite easily, see Figure 1. The strain is:

$$\epsilon_l = \frac{1}{\sin(0.5\beta)} - 1 \qquad (1)$$

Where ε_l is the strain in the geotextile and β is the angle between the surfaces of the stone.

2.2 *3-D theory*

The 2-D theory described in the previous section can be extended to a 3-D theory. In principle, this can be done for different shapes. However, most straightforward is to assume a cone penetrating into the geosynthetics and the soil underneath. In that case, the increase in area is the same as the strain presented in eq. (1) and, assuming equal strain in all directions, the average strain in one direction can be written as:

$$\epsilon_l = \sqrt{\frac{1}{\sin(0.5\beta)}} - 1 \qquad (2)$$

Comparing Eq. (2) with Eq. (1), it appears that the average strain is smaller when a cone is intruding a geotextile, compared with a 2-D situation described in Section 2.1. This means that the most critical situation is the 2-D situation when the yarns are stretched over the top of the cone, described with Eq. (1).

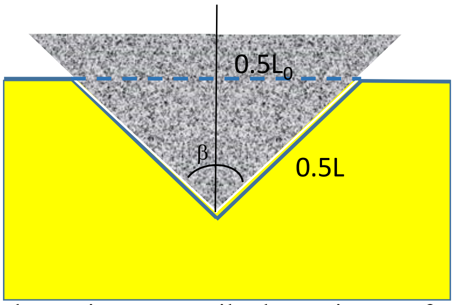

Figure 1. Elongation geotextile due to impact from L_0 to L.

3 SETUP OF THE EXPERIMENTS

A concrete cylinder of 0.8m diameter and 0.9 m high was filled with dry Mol sand. The grain size distribution is shown in Figure 2. Before each test the upper layer of the sand was loosened, see Figure 3, to avoid that ongoing densification of the sand during the tests would influence the results.

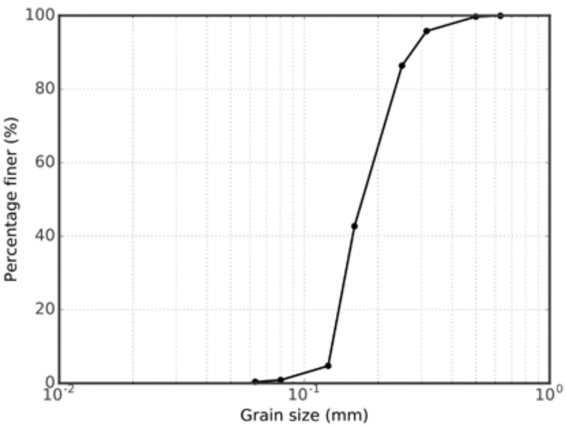

Figure 2. Grain size distribution of the sand

Figure 3. Loosening of the sand before an impact test by turning around wooden sticks.

The top was covered with a sheet of geosynthetics with dimensions 1.5x1.5m. The geotextile was fixed to the concrete cylinder with a tension rope. Rubber is glued on the upper end of the outside part of the cylinder to increase the friction. It is of importance to limit the movement of the geotextile where it is fixed to get reproducible results. The impact stone with a weight of about 40 kg was hoisted with a portal crane to the desired drop height and released using an electromagnet. See Figure 4. Different stones were used as impact stones. The basic version of this stone was a concrete cube. The maximum loading on the geosynthethics will be exerted when this cube fall on one of its corners (Figure 4 c). Less loading on the geosynthetics will occur when it falls on one of its ribs (Figure 4 d). Other stones were modifications on this cube. The angle between the surfaces was changed, from 90 degrees in the cube to 120 degrees for a flatter stone and to 60 degrees resulting in a sharp stone.

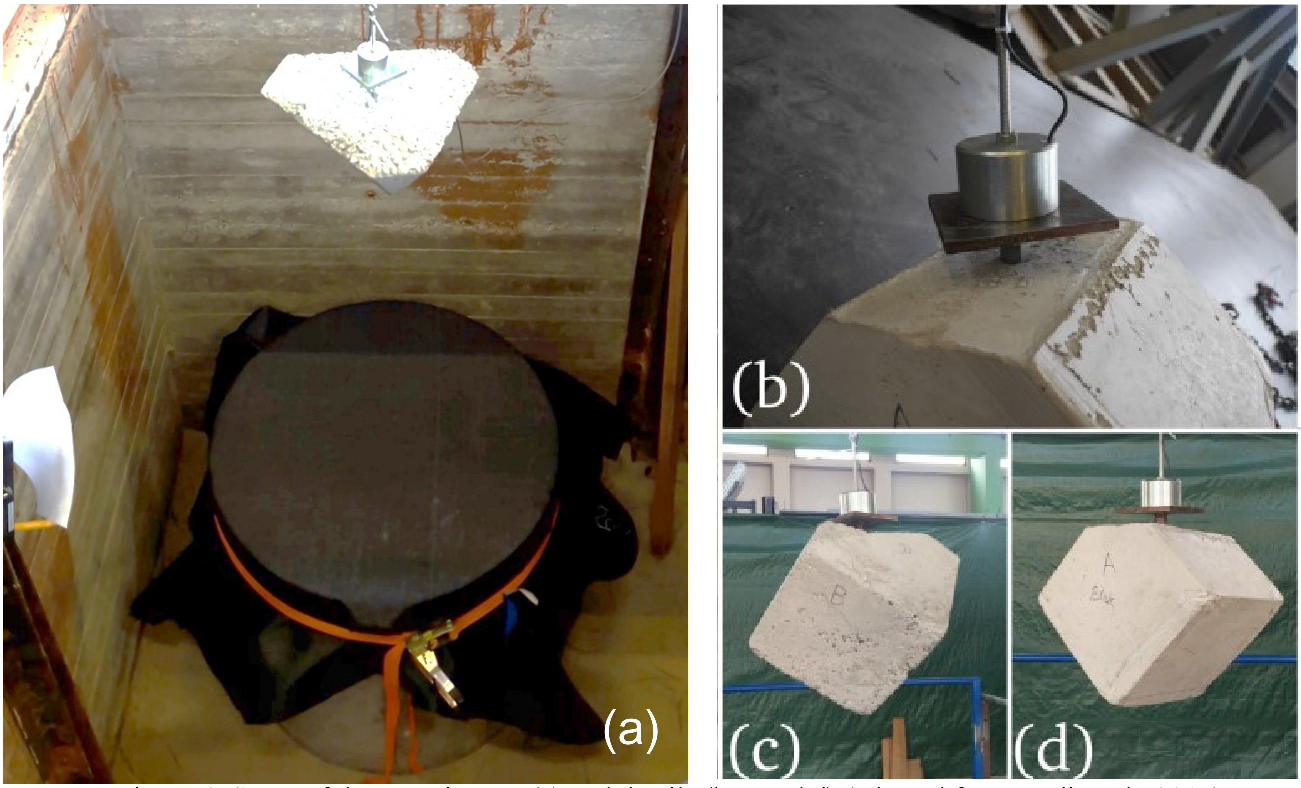

Figure 4. Setup of the experiments (a) and details (b, c and d) (adapted from Izadi et al., 2017)

The impact of the stone on the geotextile was monitored with a GoPro camera at 240 frames a second. Furthermore, the damage was recorded afterwards, see examples in Figure 5.

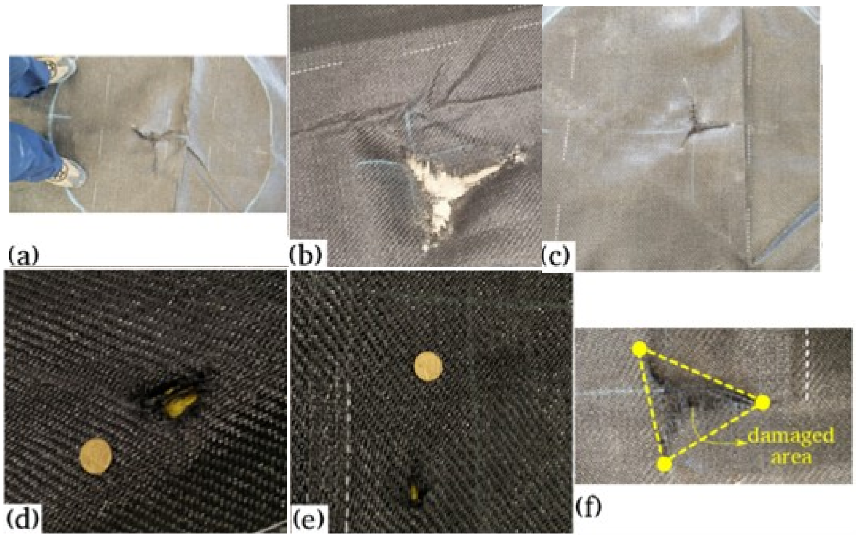

Figure 5. Examples of damaged zones after tests: block B and drop height of 3.0 m (a); block B and drop height of 2.0 m (b); block B and drop height of 1.55 m (c); block A and drop height of 4.0 m (d); block A and drop height of 3.5 m (e); calculation of ruptured area (f). (adapted from Izadi et al., 2017)

More on these tests and the results are published elsewhere (Izadi et al., 2017). Here we concentrate on some individual tests. In these tests, the influence woven versus non-woven is tested, the angle of the impact stone and the influence of more than one layer of geotextile.

The critical falling height and impact energy at damage are determined by performing different tests resulting in damage and extrapolating the results to a damage area of zero cm^2. The procedure is published in more detail in Izadi et al. (2017).

4 RESULTS

4.1 *Woven nonwoven geotextile*

Tests were performed on woven and non-woven geotextiles. Two geotextiles were tested with a comparable absorption energy per square meter. The absorption energy, E_a, is defined as:

$$E_g = 0.5 T_u \epsilon_u \tag{3}$$

Where, T_u is the ultimate tensile strength and ε_u the strain at the ultimate shear strength. The absorption energy is sometimes used to determine the robustness of geotextiles against impact. However, in these tests the results were very different for the non-woven and woven geotextile. The impact energy at which damage was noticed for impact with block B90, photo C in Figure 4, was 0.3 kJ/m^2 for the woven geotextile and 2.1 kJ/m^2 for the non-woven.

Table 1. Properties of geotextile and result of impact test

Parameter	Woven geotextile A	Non-woven geotextile B
Weight	347 gr/m^2	300 gr/m^2
tensile strength (avg)	81.4 kN/m	17.5 kN/m
ultimate strain (avg)	8.4%	50%
absorption energy	4.9 kJ/m^2	4.4 kJ/m^2
impact energy at damage (with block B90)	0.3 kJ	2.1 KJ

There are several reasons for this large difference. An obvious reason is the difference in ultimate strain. Following the, pessimistic, assumption that all strain has to be taken by the yarns underneath the stone impact, as suggested in Section 2, the 2-D strain for a stone with an angle of 90 degrees is 40%. That is less than the ultimate strain of the non-woven (50%), but more than the ultimate strain of the woven (12%). Still also the non-woven fails at certain impact energy. A possible reason for this failure will be discussed later. Another reason why there is such a difference between a woven and a non-woven geotextile, is the way the energy is transferred to the geotextile (Izadi et al. 2017). In these tests, there is also some deformation outside the contact area between the stone and the geotextile. The deformation outside this contact area can be analysed by using image processing. The result is shown for a woven and non-woven in Figure 6. For the woven geotextile, the deformation is only present in a small area parallel to the yarns that are stretched. The energy of the impact has to be absorbed in these yarns. In the directions not parallel to the yarns the geotextile is very flexible and can deform under the stone without any deformation of the geotextile further away from the stone and hardly any energy absorption will occur in these directions. The non-woven has a more uniform stress-strain behavior in all directions. As can be seen in Figure 6, the deformation is present in all directions. Consequently, more energy can be absorbed by the non-woven.

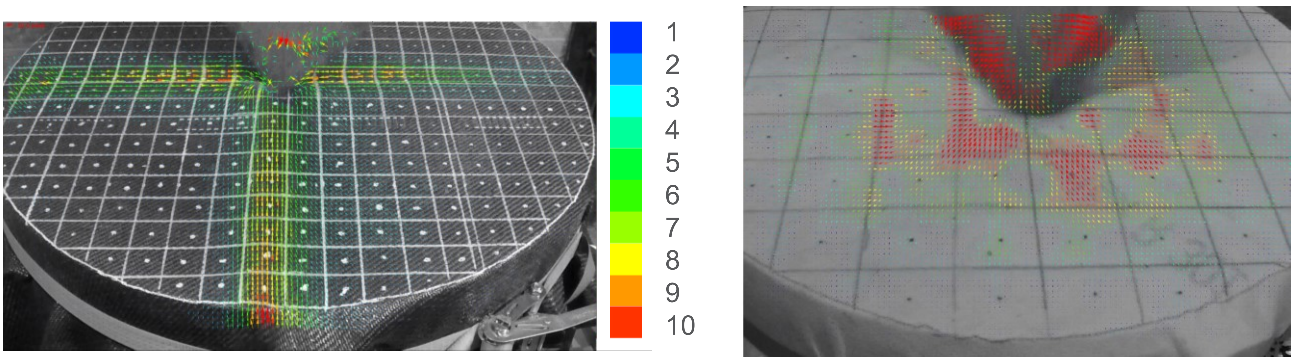

Figure 6. Deformation pattern for woven (left) and non-woven (right) geotextile during impact of a sharp stone (B60). The different colours show the amount of pixels the geotextile has moved. The pictures are originally 1920x1080 pixels (adapted from De Strijcker and Decraene, 2017).

4.2 *Influence of block angle*

Blocks of different dimensions were used. In all cases the weight was around 40kg. As mentioned before, the angle between the surfaces differed. See Figure 7 for the definition of the angle for different block types.

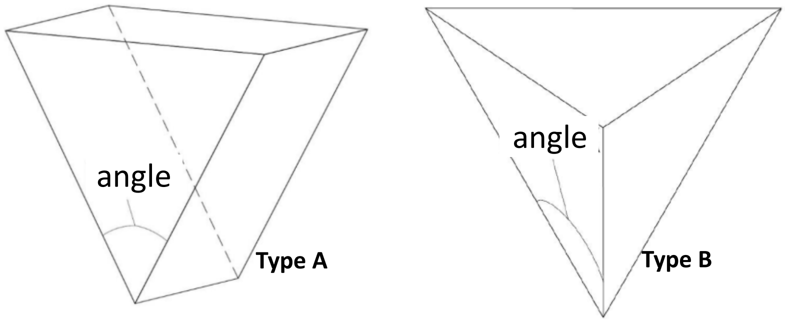

Figure 7. Definition of the angle β for Type A and Type B blocks. (De Strijcker and Decraene, 2017)

The angle β appears quite important for the damage that occurred. The relation between the critical drop heights at which the first damage was noticed, is shown in Table 2 for different blocks, block angles and geotextiles. Apart from the tests mentioned here, tests have also been carried out with a block Type A with β is 120 degrees and Type B with β is 105 degrees was also tested, but no damage occurred at the maximum falling height of 5.5 m in our setup.

Table 2. Critical falling height for different blocks, see also text. The angle β is the number behind the block type.

	Critical falling height (m)	
Block	Woven	Non-woven
A60	3.80	3.41
A90	4.50	-
B60	0.17	0.31
B90	0.72	5.25

The results show clearly that the angle β has a large influence and there also is a significant difference between the woven and non-woven. The reason for this last difference was discussed before. In general it can be stated that with a wider angle β, the elongation in the geotextile will be less, leading to a higher critical falling height.

4.3 *Two layer geotextile protection*

Some manufacturers have a two-layer system of geotextiles in there assortment. A woven and a non-woven on top of each other. The idea is that the woven delivers the necessary tensile strength and the non-woven is a kind of protective layer. One of these products was tested. The woven was a polypropylene geotextile with a tensile strength of 55 kN/m in both machine and cross direction and a maximum elongation of 15 %. The non-woven was also a PP geotextiel and had a tensile strength of 15 kN/m in all directions at a maximum strain of 50%. The connexion between the 2 geotextiles was rather loose, to minimize the interaction between the geotexiles. Tests were performed with block B90 (the block shown in Picture C of Figure 5) and a falling height of 1m. First, the single geotextiles were tested and both showed some damage. The damaged area was on average 70 cm^2 for the woven geotextile and 15 cm^2 for the nonwoven. When both geotextiles were put together, always the lowest geotextile was damaged first regardless of this was the non-woven or the woven geotextile. If the lowest geotextile was a woven, its damaged area was on average 16 cm^2, for the non-woven this was 9.5cm^2. It can therefore be concluded that the 'top geotextile' resulted in some protection, but this protection by the woven for the nonwoven is only limited. A possible reason why always the lowest geotextile is damaged first will be discussed in the next section.

5 DISCUSSION

The results show that also the non-wovens are damaged, although, following the geometric calculation described in Section 2, the maximum strain was not reached. Furthermore, the lowest geotextile was always damaged first in the '2-geotextile' test. A possible reason can be that there is not pure geometric deformation of the geotextile. During stone impact, the geotextile will be 'dragged' downwards. However, the friction between the geotextile and the sand will hamper this downward drag. The forces are sketched in Figure 8 for half of the block, since the problem is symmetric. The friction force will be large because the stone is decelerated by the impact and exerting a force on the sand. Without friction, the reaction force would be perpendicular to the stone surface penetrating the geotextile. With a friction angle ϕ, there is an angle of ϕ difference, as is shown in Figure 8.

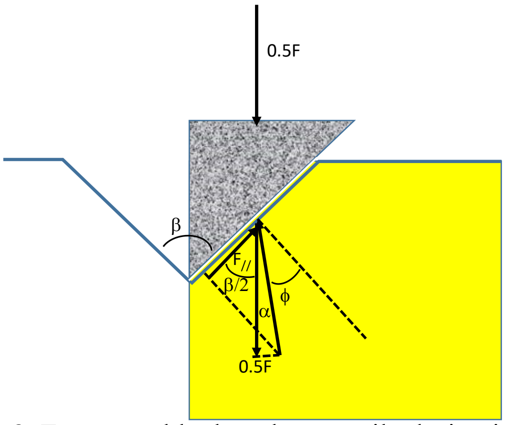

Figure 8. Forces on block and geotextile during impact.

With Figure 8 it can be derived:

$$F_{//} = \frac{\cos(\beta - \emptyset)}{\cos(\frac{\beta}{2} - \emptyset)} 0.5F \quad (4)$$

For a friction angle of 40 degrees (between the geotextile and the sand) and β = 90 degrees, the force $F_{//}$ is 0.65 times 0.5F. This means that the geotextile not only deforms because of the stone intruding into the sand, but also gets an additional tensile force because the sand is pushed to the sides and this resulted in an additional shear force on the geotextile. To estimate the value of $F_{//}$, it is necessary to estimate F. For the situation with a geotextile that is rather complicated, because the geotextile will increase the effective stress in the sand. To get a first approximation of this force, we can assume the stone is falling in sand without geotextile. For that situation, we can use the classical bearing capacity formula for a shallow strip footing without cohesion of the soil and at the surface:

$$F = \alpha 0.5\gamma' B A N_\gamma \quad (5)$$

Where γ' is the 'effective' density, B the width of the footing, A the area and

$$N_\gamma = 2(N_q + 1) tan\phi \quad (6)$$

and

$$N_q = e^{\pi.tan\phi} tan^2(45 + \frac{\phi}{2}) \quad (7)$$

The factor α depends on the geometry of the stone and is 1 for a strip footing and 0,6 for a square footing. In a spreadsheet program, the impact velocity of the stone was calculated from the falling height. As soon as the stone hits the sand, it was calculated how far the stone has penetrated 0.005s after impact. Since the angle β is known, the area A can be calculated and with Eq. (5) the resistance force, which leads with Newton's law to the change in acceleration and a change in velocity and displacement. The displacement is used to calculate the next step using the same time interval of 0.005s. The calculation is repeated until the stone comes to a standstill. In the experiments, the stone sometimes bounces, but that is not incorporated in this calculation. The friction angle in the sand is found by calibration of the solution with impact experiments as described above but without geotextile. A friction angle of 43 degrees resulted in a good agreement between the measured and calculated penetration. This is quite a bit higher than the friction angle found in shear box tests for this sand 30.3 degrees, but, as mentioned before, the geotextile results in extra vertical stress just next to the stone, which is not taken into account in the calculation.

Running this calculation for block B90 and a falling height of 5.25 m, the falling height that led to damage of the geotextile, results in a tensile loading according to this mechanism of 17.5 kN/m, which is equal to the tensile strength of the geotextile of 17.5 kN/m. For block A60 the tensile loading at the critical falling height of 3.41 m is only 11.5 kN/m, but here the strain due to the deformation of the geotextile is already 41% for the 2-D situation. At the corners of the block, the deformation will be even higher, so that damage at one of the corners can be expected.

In this simplified calculation just one force is calculated. In reality, this force is exerted as a shear stress along the geotextile that becomes larger closer to the lowest point of the stone. Only at the lowest point, it will have its maximum value and therefore the geotextile will be damaged there first.

The calculation method presents an explanation why the lowest geotextile fails in the two geotextile tests. The upper geotextile is between 2 relatively smooth layers, the concrete block and the lowest geotextile. It can slip between these layers. The lowest layer is in contact with the sand that as explained above will lead to extra tensile forces.

The results also show clearly that when the block causes an elongation larger than the maximum strain, damage will occur at only small falling heights, as can be seen in Table 2, the results of the B60 block.

6 CONCLUSIONS

Stone impact on geotextiles was investigated. Tests were performed with different stones with all have a weight of around 40 kg. From the results of the tests, the following conclusions were possible:

1. The angle β as defined in this paper has a significant influence on the results of the tests. 'Sharper' blocks (with small values of β) create more damage than 'blunt' blocks. Especially for wovens the difference in critical height was remarkable.
2. Blocks of 40 kg with β values larger than 90 degrees (105 and 120) did not create damage on woven or non-woven geotextiles, even for a drop height of more than 5 m.
3. A woven is more vulnerable to damage than a non-woven due to the lower ultimate shear strain and the localized strain. The woven geotextile will absorb the impact energy parallel to the yarns. For a non-woven this absorption will be over an area all around the impact. This was seen from the deformation pattern (see Figure 6).
4. The geometric elongation as described by SBR-CUR (2017) is an important criterion. Yet the friction of the subsoil with the geotextile seems to be another source of loading on the geotextile. The mechanism, as described in the Discussion of this paper explains why a geotextile is damaged even if the elongation according to the geometric criterion is less than the ultimate shear strain. Furthermore, it presents an explanation why it was found that in a 2 geotextile test with composite material always the lowest geotextile was damaged first, regardless if this was the woven or the non-woven of the composite material.

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