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A laboratory investigation on the impact resistance of a woven geotextile

Ehsan Izadi[a,b,*], Tijl Decraene[c], Steven De Strijcker[c], Adam Bezuijen[a,d], Dirk Vinckier[c]

[a] Laboratory of Geotechnics, Ghent University, Technologiepark 905, 9052 Zwijnaarde, Belgium
[b] Design Management Office, GeoSea NV, Haven 1025, Scheldedijk 30, 2070 Zwijndrecht, Belgium
[c] Department of Industrial Technology and Construction, Ghent University, Campus Schoonmeersen, Valentin Vaerwyckweg 1, 9000 Gent, Belgium
[d] Deltares, Boussinesqweg 1, 2629 HV Delft, The Netherlands

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ABSTRACT

This paper focuses on the impact resistance of geotextiles when subjected to impact loadings induced by dropping of stones. Such scenarios occur when geotextiles are used as a protective measure for fine granular material where is prone to be washed away. Usually, these geotextiles are restrained by placement of stones on top of them. A laboratory testing program is performed to expose a woven geotextile under dropping of a concrete block with various dropping energies and geometries. The induced damage on the geotextiles is inspected after the drop. Results indicate that as the drop energy increases, not only the possibility of puncturing of geotextiles increases but, in case of puncturing, the punctured area of geotextile expands as well. In addition, it is found that the geometry of the concrete block, where it collides on the geotextile, plays an important role on the survivability of geotextiles. In addition, PIV analysis has been performed to better understand the deformation pattern of the geotextile under impact loading. Based on the PIV results a simple scheme is suggested to estimate the drop energy threshold that the geotextile can survive under certain block geometry.

1. Introduction

Over the past decades, geotextiles have been extensively used in various geotechnical and geoenvironmental applications such as soil separation, filtration, drainage, reinforcement as well as land reclamation projects (Holtz, 2017; Keller, 2016). The damages due to long term of short term loading on geosynthetics have been studied extensively over the past decade (Consoli et al., 2017; Ewais et al., 2014; Vieira and Pereira, 2015). However, amongst all types of damages, installation damage of geotextiles has not been fully studied yet. Depending on the application of geotextile, the source of damage can differ: passage of roller compactors on the soil layer above geotextile, dropping of stones on geotextiles for restraining purposes and abrasion of geotextiles during installation on angular coarse grained soils. If the possibility of damage during installation is not considered in the design stage, the designed structure may not necessarily function as desired and in some cases, such damages can cause large failures in the structures.

The problem of geotextiles and geosynthetics survivability is not a new issue and has been studied (Allen and Bathurst, 1994) and standardized since the 90s (ISO10722, 1998; BAW, 1994). ISO 10722 standard (ISO10722, 1998) introduces a set of instructions in order to simulate the damage that potentially can occur due to the installation of geotextiles. Based on ISO 10722, the composite of granular material and geotextile is firstly subjected to impact loading, and then the geotextile will be subjected to the tensile strength test to investigate the strength loss induced by the impact load. Such procedure simulates the process of compaction of the soil layers upon geotextiles by means of vibratory rollers. However, the validity of such standard can be questioned since various parameters affect the strength loss of the geotextile such as angularity, type, and composition of the granular material; thickness of the soil layers and the magnitude of the dynamic loads applied to the composite material. Paula et al. (Paula et al., 2004) studied the effect of various granular materials on the damage during installation of three different geotextiles in a laboratory study. Hufenus et al. (Hufenus et al., 2005) conducted a comprehensive study on the survivability of a broad range of geotextiles under various conditions and reported that the survivability of the geotextiles depends mainly on the material which geotextiles is made of. They further reported that grain size distribution, the geometry of the soil grains and compaction energy all influence the damage imposed on the geotextiles during the installation phase. Another important finding is that the stiffness of the damaged geotextiles was maintained, although the ultimate load and/or ultimate strain reduced in some cases. The recent studies (Hufenus et al., 2005; Paula et al., 2004) show that the installation damage of geotextiles should be prevented as much as possible, and if not, the

* Corresponding author. Laboratory of Geotechnics, Ghent University, Technologiepark 905, 9052 Zwijnaarde, Belgium.
E-mail addresses: Ehsan.izadi@UGent.be, Izadi.Ehsan@DEME-group.com (E. Izadi).

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damages need to be considered in the design process or the design need to be reviewed for safety measures.

In all the aforementioned studies the testing condition was designed in such a way to represent the application of the geotextiles as a horizontally placed reinforcement, however, the loading type during installation differs based on the application of geotextiles. In off-shore earth-made structures which are subjected to cyclic wave action and hydraulic forces, there is always a concern on washing away of earth materials. To protect coastal areas, geotextiles are placed upon the earth material and to fix the soil in place, a rip-rap revetment is built on the geotextiles. Presumably, the most important challenge here is to choose a suitable geotextile and/or limit the drop energy, so the geotextile can survive the installation stage with minimum or no damage. In the operation life of a geotextile, even a small puncture can cause erosion, which may result in disastrous damage and large failure.

2. A review on the literature

Although the subject of survivability of geotextiles under impact loads is not a new subject, it has not been thoroughly investigated and the loading on a geotextile under impact loads is still not well understood. Probably, the first set of standards for testing of geotextiles under impact loads was developed by Federal Waterways Engineering and Research Institute of Germany (BAW, 1994). The test apparatus in BAW's guidelines is composed of a box with horizontal dimensions of 80 × 80 cm and depth of 31 cm filled with compacted sand which the geosynthetic on top of it. The geosynthetic is fixed at the periphery of the sand bed. Once woven geotextiles are tested, it is advised to place a thick rubber sheeting on top of the geotextile prior to clamping to provide a better grip and restrain of the geotextile. Above the geotextile, there is a central rammer sleeve in which a 76 kg rammer with specific edge-cut. The drop should be performed at prescribed energy levels. After the drop is made, the geotextile is taken out for visual examinations. According to BAW's recommendation, any visual damage, which reduces the filtration capability of the geosynthetic must be regarded as a damage.

In a comprehensive study, Wong et al. (Wong et al., 2000) gathered the results of 784 drop tests using a standardized block in order to determine what parameters are dominant in the determination of the survivability of the geotextiles. The Drop heights in the tests were 0.5 and 2.5 m, and two woven and three non-woven geotextiles were included in the testing program. The geotextiles were laid on different types of soils with different layer thicknesses and the effects of both horizontal and sloping grounds were considered. They reported that existing index tests such as the CBR test and tensile strength tests do not properly represent an index for the survivability of the geotextile. Instead, the survivability of a geotextile corresponds to the level of energy that a geotextile can absorb under impact loading.

Kendall et al. (Kendall et al., 2014) studied the survivability of four different polyester grade staple fiber geotextiles under the impact of a concrete block with a mass of almost 1000 kg and from 2.5 m dropping height. Unlike the study of Wong et al. (Wong et al., 2000), they concluded that the deformation energy measured in CBR test can be an effective representation for survivability of a geotextile. They have defined three zones in drop energy vs. CBR energy level as “sub-critical zone”, “intermediate zone” and “critical zone” in which the possibility of puncturing is very low, fair and high respectively. However, there is no clear distinction between the zones and the intermediate zone, in which the likelihood of puncture is fair, is relatively wide. In addition, the effect of the sharpness of the tip of the stones is ignored as they just used a standardized block with a certain geometrical tip. Therefore, the results remain valid for the specific block sharpness that was in use. In another similar study, Kendall et al. (Kendall and Cheah, 2014) carried out drop tests using the same test scheme on two types of nonwoven geotextiles: staple fiber and continuous filament. It was reported that greater puncture resistance was observed in staple fiber geotextiles. Cheah et al. (Cheah et al., 2016) conducted a very similar testing scheme as conducted by Kendall et al. (Kendall and Cheah, 2014; Kendall et al., 2014), however, they conducted drop tests on four staple fiber (SF) geotextiles and three continuous filament (CF) geotextiles with different levels of ultimate strength, elongation, and mass. The used test setup was identical to the setup described in the studies of Kendall et al. (Kendall and Cheah, 2014; Kendall et al., 2014); nevertheless, they conducted CBR tests on the geotextiles after the drop to assess the strength loss of the geotextile due to the impact load and as a consequence the abrasion caused by the impact from either block or subsoil. The geotextile samples were cut from the four corners of the master geotextile sample. They have found that geotextiles with better mechanical properties (higher mass or ultimate tensile strength) do not always outperform the geotextiles with lower mechanical properties. Moreover, they deduced that strength reduction for CF geotextiles was considerably larger (between 20% and 50%) than the strength reduction of SF geotextiles (between 0% and 5%).

Abrasion is another factor influencing the ultimate strength of geotextiles and geomembranes studied by a number of researchers (Cheah et al., 2016; Fox and Thielmann, 2014; Frost and Karademir, 2016; Heerten, 2008; Huang, 2008; Huang et al., 2007; Rosete et al., 2013; Saathoff et al., 2007). Geotextiles may be subjected to abrasion (thinning of filaments due to shearing away of materials), which has a negative effect on the impact resistance of the geotextiles. For instance, Huang et al. (2007) simulated abrasion in a flow chamber to investigate the abrasion damage of woven geotextiles. They have reported that the tensile strength of the geotextile can decrease up to 61% after exposing the geotextile to abrasive flows for 24 h.

Reviewing the literature shows that several factors affecting the puncturing behavior of geotextiles. Wong et al. (Wong et al., 2000) listed the parameters affecting the impact resistance of the geotextile. Also we have added some more parameters affecting the impact resistance and in summary the factors can be remarked as geotextile type and characteristics such as mass, ultimate tensile strength, elongation at failure point, polymer type and thickness; the subsoil condition including density, grain size distribution, angularity of the grains, moisture content, stiffness parameters, thickness and properties of the soil layer underneath and/or above the geotextile and the slope of the ground on which geotextile is placed on; falling height and mass of the stone being dropped on the geotextile, the angularity, shape and surface roughness of the stone and the probability of dropping on its sharpest point on the geotextile. Furthermore, the type and distance of restraining of geotextile at the peripheries matters as geotextile can be fixed or subjected to pretension prior to the drop test. Note that the fixing of geotextile itself is a relative phenomenon and achieving a pure and uniform fixing is very difficult. In the previous studies and standards (Cheah et al., 2016; BAW, 1994; Kendall and Cheah, 2014; Kendall et al., 2014; Wong et al., 2000) there is no information on how successful was the fixing of geotextile and whether any movement of geotextile was observed at the peripheries during the impact or not. Only BAW (BAW, 1994) recommends using rubber sheeting at the peripheries when geotextile is used to provide more grip to fix the geotextile. Note that fixing the geotextile is very important as in the case that movement of geotextile occurs at the peripheries, a larger puncturing resistance will be achieved. In addition, a free fall mechanism for the block should be provided so no external factor (except air resistance) can alter the free-fall velocity of the block.

The geometry of the dropping stone, especially at the point it falls on geotextile, is an important issue. Previous studies neglected the effect of the “sharpness” of the stone tip. Obviously, with an identical drop energy and testing condition, the sharper the tip of the stone, the more likelihood of the damage induced by the drop. In the real installation process, not all the stones have the same sharpness and puncturing of geotextiles does not always fail the operation efficiency of the geotextiles. Chew et al. (Chew et al., 2003) proved if the size of the puncture is smaller than a certain size in such a way that allows the