Geotextiles and Geomembranes 42 (2014) 374–393

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Geosynthetics for waterways and flood protection structures – Controlling the interaction of water and soil☆

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ARTICLE INFO

Article history:
Received 9 March 2014
Received in revised form
2 June 2014
Accepted 3 June 2014
Available online 27 June 2014

Keywords:
Geosynthetics
Impervious lining
Filter
Containment
Erosion
Scour

ABSTRACT

The interaction of water and soil has been both a blessing and a curse in all times within living memory. Water is the origin of life but is also threatening life when appearing unboundedly. Therefore mankind has always worked hard to benefit from water resources on one hand and to deal with the threat of flooding on the other hand. For both, to protect the land and to allow for beneficial uses like irrigation or navigation, often special measures are necessary to keep the water within certain bounds. Structures to achieve a permanently stable situation like irrigation and navigational canals, river training or flood protection measures need suitable material, carefully thought out design and accurate execution. Often a decision has to be made among competitive approaches to optimize such structures. In many cases, geosynthetics can support or improve the functionality and sometimes only with geosynthetics the desired result can be achieved.

Geosynthetics can provide strength and flexibility, imperviousness and drainage, durability and robustness or controlled degradation. All these properties can be of use to handle the many occurrences of interaction of water and soil. Surface water has to be guided or to be kept off; percolating water should be controlled to avoid internal erosion effects should be restrained by appropriate filtration. To guarantee well functioning in general, also chemical and biological aspects have to be considered like ochre formation, root penetration and population by any kind of species. The German Federal Waterways Engineering and Research Institute (BAW) has gathered experience with geosynthetics in hydraulic applications since more than 40 years. These years revealed the capabilities of geosynthetic solutions and simultaneously emphasized the need of careful selection, design and execution.

A large variety of geosynthetic fabric and structures is available. To control the interaction of water and soil many different attributes are required, e.g. membranes for impervious lining, filter sheets for erosion control, different kinds of mattresses or wrap-around structures, voluminous elements from sandbags to mega containers for protection, training or immediate repair. In many cases geosynthetics can be designed to control the interaction of water and soil according to the individual and local requirements to allow for an excellent execution of waterways and flood protection structures.

1. Introduction

We all remember the Great East Japan (undersea) Earthquake in March 2011. The earthquake triggered powerful tsunami waves that reached heights of up to 40.5 m and which, in the Sendai area, travelled up to 10 km inland. The hazard resulted in nearly 20,000 fatalities as well as over 125,000 buildings damaged or destroyed. And we remember a similar event, the 2004 Indian Ocean tsunami, triggered again by an undersea megathrust earthquake that hit several countries. With these and similar hazards, nature demonstrates the power of water. In such events, water does not only cause flooding, take lives and demolish goods but proves also to be stronger than soil, often even stronger than rock.

But leaving the coast and the valleys to the water and settling on hills or in the mountains would be no solution either. Water also comes from above. And if there is too much of it, again soil and rock are weaker than water. Hundreds of rain-induced landslides and mud avalanches in the world threatened lives and destroyed property. In any respect of human living – housing, farming, traveling and leisure – it is desirable to have water and ground in balance. Unfortunately this is not a persistent condition in many

☆ This is the Mercer Lecture.

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http://dx.doi.org/10.1016/j.geotexmem.2014.06.003
0266-1144/

places of the world that are populated by mankind. No water prevents (human) life, but too much water as well. In the first case, water has to be transported from deep under the ground surface or from far away. In the second case, the water course has to be controlled.

Measures to control the water course need sufficient strength against water pressure and water flow. Soil and even rock have only a limited resistance against these hydraulic effects, therefore the interaction of ground and water is the main issue wherever water is or should be kept in certain bounds. Borders of surface water are the coast, river banks, canal embankments or dikes – so most confinement of water is made of soil and rock. Knowing the vulnerability of soil to water, mankind tried to improve its resistance against water since the beginning of settlement and building. Even rock may not withstand the water forces: rock pillars at the Danish and the Australian coast vanished in comparably short time (Fig. 1).

But we are not powerless. The village Fudai in Japan was saved because a mayor ignored criticism and spent a lot of money on a gargantuan floodgate (Hosaka, 2011). In this manner, possibilities to control the interaction of water and soil can be found in many cases. Certainly, we need careful planning and intelligent design in each individual case. The floodgate in Fudai was the right solution for the rather narrow valley and would not match in a plain. So we should always try to find the matching solution – sometimes it needs intricate tracks to reach one's goal.

2. Interaction of water and soil

2.1. Actions

Currents and waves come into mind when thinking of hydraulic loads in rivers and at the coast. Therefore, at first sight canals appear to have the benefit of no flow like in rivers and so one reason of erosion and scour seems to be omitted. But we must not forget the ships that can create heavy loads on the bank. Propeller and bow thruster jets as well as return current and transversal stern wave possess strong erosive energy, which asks for an appropriate protection.

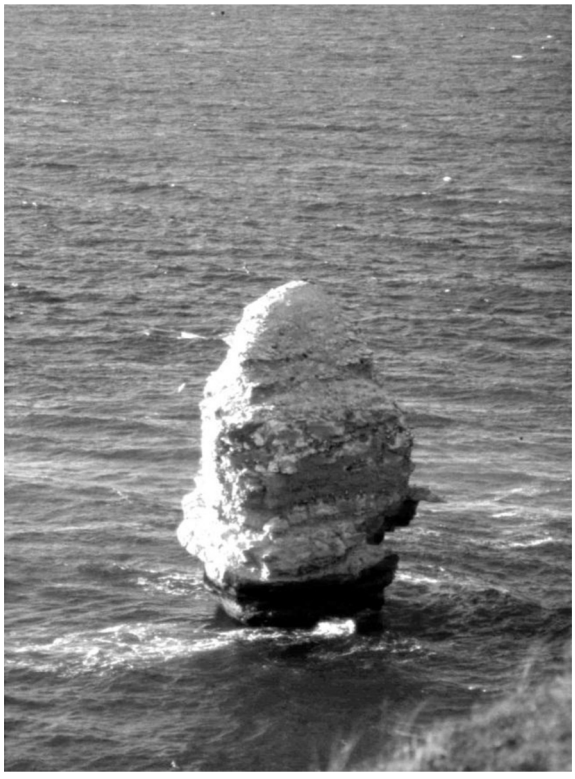

Fig. 1. Skarreklit, Denmar, vanished 2005.

In rivers and at the coast there is the risk of flooding. Due to water levels high above the normal there is interaction of water and soil in areas where it is not expected. Therefore, protection measures should be discussed also for extreme and rare events. Even seemingly mild hydraulic load from rainfall can be the reason for severe impact on structures and ground. Surface erosion is an extraordinary threat to all earth structures, because initially only tiny rills can develop to deep gullies or channels, which can reduce their stability. And intense rainfall can be the reason for hill slides and mud avalanches.

Furthermore there is a kind of flow we cannot see: groundwater and seepage water percolating through the ground and the earth structures. From unexpected and unwanted "springs", we can suspect the (often negative) interaction of percolating interstitial water and soil, which might result in sand boils, liquefaction, piping or internal erosion. To get more information on such interstitial flow, we can try to model it, either physically or numerically, but we never can be sure to know all about it. We only can hope to get enough information to plan countermeasures.

2.2. Countermeasures

So what can we do against such unwanted effects? To mitigate the detrimental interaction of water and soil, either the action or effect of the water has to be reduced or the resistance of the ground has to be increased. The first could be addresses as "active" measures while increasing the resistance is a "passive" method.

Active methods are all measures that alter the flow pattern (of surface water as well as of pore water) or to reduce the wave intensity. Also limiting the hydraulic gradient or avoiding excess pore pressure would reduce the effect on the ground. Structural measures to alter the surface flow pattern are elements to divide the runoff, check dams and river and coastal training works like sills, breakwaters, groins or longitudinal dikes. Drains affect the pore water flow to avoid internal and surface erosion. They also can help to prevent excess pore water pressure and thus the risk of fluidization. Impervious elements prevent any interaction of ground and water. Active measures are dealt with in the sections "Keep the water away", "Control the interstitial water" and "Direct the surface water". Active measures might be the more intelligent way to influence the interaction of ground and water, but often the situation in situ compels to other solutions, in particular if we are confronted to deluge-like quantities of water.

Increasing the resistance is the alternative and often the only measure if no alteration of actions can be realised. Also the comparison of costs may lead to such a decision. Strengthening the ground comprises an increase of the overall stability of an earth structure or an increase of the resistance of the single element that is affected by hydraulic action. Passive measures are dealt with in the sections "Strengthen the structure and the ground" and "Protect the surface against hydraulic impact".

3. Material

3.1. General

Discussing geosynthetics for waterways and flood protection covers a large variety of material. Many kinds, woven and nonwoven, extruded mats and grids as well as impervious products like polymeric and bentonite membranes are used in the various