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CLIMATE CHANGE AND EXTREME WEATHER CONDITIONS: THE ROLE OF GEOSYNTHETICS SECURING FLOOD DEFENCES AND COASTAL PROTECTION

Introduction

Climate change has brought rapidly changing hydraulic conditions, with heavier rainfall, more severe storms, higher river discharges, increased flow velocities and wave overtopping. With nearly a billion people living in low-lying areas near rivers and coastlines, securing and improving flood defences and flood protection schemes has become a global challenge. Integrating geosynthetics on a larger scale into designs can lead to better, faster and/or cheaper construction of new flood defences, levee reinforcements or coastal protections. This has the potential to considerably boost global flood protection programs. This paper illustrates the benefits and added value of applying geosynthetics in flood defences, aiming to encourage the use of these materials by designers, contractors and authorities. This paper is a shorter and modified version of Gerritsen et al. (2023).

Climate change observations and impact

Based on data, global sea levels have risen about 0.20 m during the last 100 years, and the rate of rise is accelerating. The implications and consequences of the rising sea levels for people on earth are enormous. The Intergovernmental Panel on Climate Change (IPCC, 2022) has made global assessments of potential scenarios, that predict a sea level rise between 0.3 m and 1.5 m by 2150, depending on the climate scenario. Figure 1 combines measurements and predictions of sea level rise, clearly illustrating the major challenges in reinforcing existing, or realising new flood defences.

The predictions of sea level rise obviously contain uncertainties; nevertheless, the values will have significant implications for the safety, liveability and sustainability of residential, commercial and agricultural areas. Effects such as dune and beach erosion along coastlines, due to high-water conditions, will become increasingly frequent and intense.

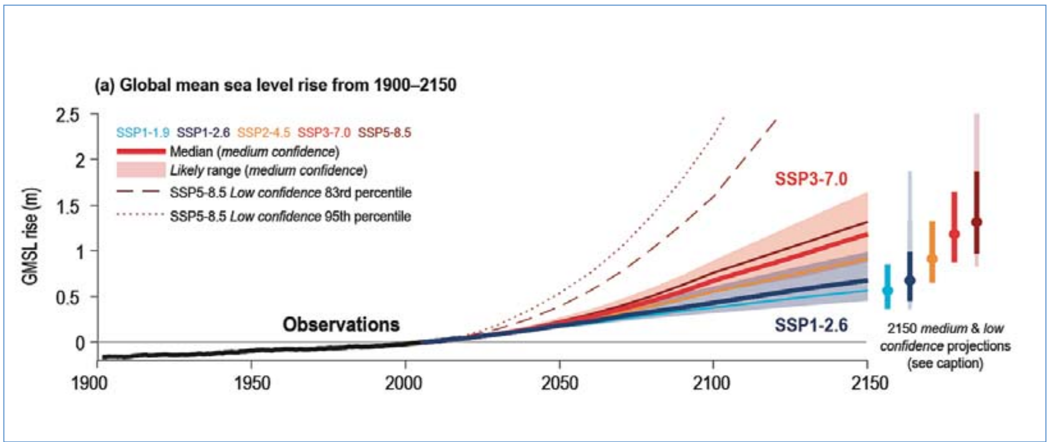

Figure 1 – Projected Global Mean Sea Level Rise (1950-2150) under different SSP scenarios, given in different colours and reliability range by IPCC (2022), Box TS.4 Sea Level, Figure adapted by Deltares.

Figure 2 – Schematic section of a high-performance flood defence structure with soil reinforcement, geosynthetic clay liner as a barrier, nonwoven geotextile for filtration and separation and erosion control products on the embankments. Other possibilities (not shown) are erosion control mats and filter layers below a stone revetment.

The global damage costs that result from floods due to sea level rise are expected to increase significantly. Jevrejeva et al. (2018) show that with a 0.86 m sea level rise (RCP8.5 scenario, median value) and without additional measures for flood defences, the worldwide estimated flood damage costs in the year 2100 are 11600 billion euro/year. However, implementing measures to improve coastal protection, could potentially reduce these annual costs by about a factor 10. Despite this reduction, the costs remain substantial, indicating that the impact of sea level rise and consequential costs of flooding will be very high for all coastal areas worldwide.

Haasnoot et al. (2018) listed possible measures for adaption to the accelerated sea level rise in the Netherlands.

1. Higher and wider flood defences;
2. More beach nourishment;
3. Structural measures to maintain the fresh water supply and water safety;
4. Considerably higher frequencies in closing storm surge barriers.

Applying geosynthetics can have a significant potential for adaptation measures. In this paper we will focus on applications in flood defence structures (1) and coastal defence (2). Building with geosynthetics is highly sustainable, enables the use of local less suitable soils and building in difficult circumstances.

ABSTRACT

In the coming decades, it will be a great challenge to respond effectively to the global climate change, causing sea level rise, heavy rainfall, storms and extreme droughts. This response involves both climate mitigation, through CO_2 reduction, and climate adaption, which requires adjusting our physical surroundings to the changed environmental conditions. Geosynthetics can play a significant role in addressing these challenges. Geosynthetics contribute to CO_2 reduction, thereby limiting climate change. Additionally, applying geosynthetics in flood defences mitigates issues like higher hydraulic loads, erosion and stability concerns. This paper describes some valuable applications of geosynthetics for adapting and creating safe and resilient living areas.

Geosynthetics for flood defences

Geosynthetics can serve various functions in flood defences, like erosion protection, reinforcement, separation, sealing, drainage and filtration. Their potential contribution to levee reinforcements is considerable (Gerritsen et al., 2019). However, the complexity of levee reinforcements becomes larger due to higher safety requirements, the need to preserve landscape and buildings, and more severe hydraulic conditions. Also financial budgets for flood control are under pressure. Consequently, alternative and innovative techniques are increasingly seen as necessary or highly desirable.

Figure 2 shows a cross section of a flood defence structure, showing multiple geosynthetics for various functions. Geosynthetic applications reduce the use of primary soil building materials, enables the use of locally available soil, and significantly minimises the environmental impact through lower CO_2 emissions compared to traditional building methods.

To ensure adequate flood defences in the future, the frequency of levee reinforcements in the coming decades will increase. It is therefore important to design the structures in a way that allows for easy adaptation during the next levee reinforcement. This involves ensuring that (geosynthetic) materials can be easily removed from the ground or that structures are extendable.

Figure 3 – Filter construction using a non-woven geotextile below a placed block revetment on the slope and rock in the levee toe (Markermeerdijken, The Netherlands).

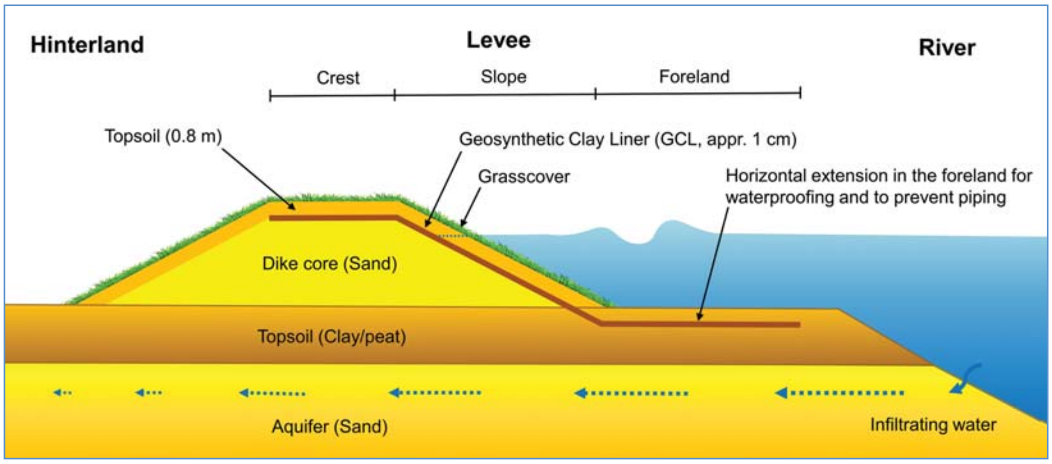

Figure 4 – Geosynthetic Clay Liner (GCL) installed on the levee slope, crest and horizontally in the foreland to enlarge the seepage length from the flood defence base, mitigating the risk of piping.

GEOTEXTILE FILTER CONSTRUCTIONS UNDER STONE REVETMENTS

Stone revetments play an important role in protecting levees and coastlines. The selection of stone gradings, ranging from 10 kg to over 3 tonnes, depends on the hydraulic conditions. To ensure their proper functioning, it is essential to apply an adequate filter layer system that prevents gradings or subsoil to be washed away. Traditional filtersystems can result in layer structures of 1-2.5 meter thickness.

Using a geotextile filter is an efficient measure below stone revetments, which can save between 0.3-1.0 m of granular filtermaterial. In addition to these savings, the use of geosynthetics can reduce the CO_2-emissions with appr. 40-50%, due to the significant reduction of the transport of materials. Geosynthetic filter systems in rock revetments have become widely adopted in hydraulic engineering projects, due to their easiness of installation and cost efficiency. Figure 3 gives an example of the construction of a placed block revetment on a nonwoven filter on the slope and rock in the levee toe. For the application it is important to consider the filter and application rules from SBRCURnet (2017) and to ensure adequate robustness to avoid damage by sharp stones as decribed by Bezuijen and Izadi (2018), Izadi et al. (2018), Bezuijen (2023).

WATER BARRIERS WITH GEOSYNTHETIC CLAY LINERS (GCLS)

As an alternative for a 1 m thick layer of natural clay, it is possible to implement a Geosynthetic Clay Liner (GCL) in river levees. These mats, with a thickness of approximately 1 cm, consist of a cover and bottom geotextile with high quality bentonite in between. GCLs can be used to seal the foreland as an anti-piping measure, or in the levee itself (Figure 4). Apart from cost savings, Von Mauberge et al. (2022) show that the application of GCLs offers several significant advantages over natural clay such as sustainability (reduced energy requirement and CO_2 emissions for transport), faster construction (less deep excavation and no need for dewatering) and more use of nearby soil. Due to the swelling capacity of the bentonite, the mat is self-healing to a certain extent. In Germany, multiple projects with GCLs in flood defences have been executed in the last decades, for example along the Oder. In the Netherlands, two pilot projects have been initiated by Water Authority Limburg. In Beesel, GCLs have been installed on the crest and slopes of the levee. In Neer, the CGLs were installed in the foreland of the levee to extend the seepage length and prevent piping.

GEOSYNTHETIC SAND CONTAINERS (GSCS) FOR COASTAL PROTECTION AND REDUCING BEACH NOURISHMENT

Sand-filled geotextile containers can be filled on-site and installed on beaches to stabilize the coastline (Figure 5). These containers can also be used in deeper water to prevent scour or to fill up large scour holes. Scouring can occur in riverbeds during floods with extreme discharges, in harbours, or due to hydraulic turbulence around structures like dams and outlet structures.

In the area of Lubmin on the Baltic Sea, a hidden underground protection structure has been built over 2 km of coastline using Geotextile Sand Containers (GSCs). A total of 34,000 sand-filled elements, weighing approximately 1.4 tonnes each, were installed (Figure 6). The structure, being covered with sand seamlessly blends with the coastline, without restrictions for tourism and beach life (Pries, 2022).

Geotextile elements are regularly used as breakwater core, dune foot defence structures, erosion protection or water retaining structures as shown by Pilarczyk (2000) and Bezuijen and Vastenburg (2012). These applications are used world wide. The use of geotextile elements in coastal or flood defence structures has the potential to significantly reduce the risks and effects of beach and dune erosion. This may reduce the number of beach nourishments, costs and maintenance frequency of beaches and dunes after severe storms.

EROSION PROTECTION WITH 3D STRUCTURE MATS

As a result of climate change, there will be higher water levels, stronger currents, increased waves and heavier rainfall. Therefore, more robust and intelligent erosion protection systems for flood defences are increasingly important. Robust erosion protection is crucial in cases of overflowing levee structures. One effective method of erosion protection is the use of three-dimensional geosynthetic structure mats, which reinforce the topsoil layer on embankments (see Figure 7). These mats, known as High Performance Turf Reinforcement Mats (HPTRMs), provides protection of the bare soil or early vegetation, thus providing extra resistance to erosion. This prevents the washing away of grass seeds or young vegetation, ensuring homogeneous germination, resulting inthe development of a better-quality grass vegetation.

In addition, the structure mats provide a long-lasting reinforcement of the top layer within the root zone. This may be particularly necessary at locations where higher loads are expected, such as breaking waves, overtopping water and strong currents. Special attention should be given to slope transitions, where the loads are often higher and the strength is less.

SOIL REINFORCEMENT FOR EMBANKMENT STABILITY AND STEEP SLOPES

Raising embankments on soft soils can cause stability problems. A regularly applied solution is the installation of high-strength soil reinforcement at the base of the embankment, known as 'basal' reinforcement. The strength of this reinforcement typically ranges from 300 to 1500 kN/m. Along the German-Polish border, along the Oder, a 3 km levee stretch was reconstructed to withstand more extreme flood conditions. In order to ensure sufficient stability of the new levee, a high strength geogrid of 1000 kN/m was installed as a basal foundation reinforcement (Figure 8).

Another application of geosynthetics on flood defences is the realisation of steep slopes to reduce land usage. In many cases, there are existing structures such as houses adjacent to these flood defences. As an alternative to vertical retaining walls of steel or concrete, geogrid reinforced soil structures can be used to create a steep slope, see POV Macrostabiliteit (2018) and CUR/CROW (2018). Retaining walls utelizing geosynthetic reinforcement are generally flexible and are able to deform together with subsoil settlements. This makes geosynthetics

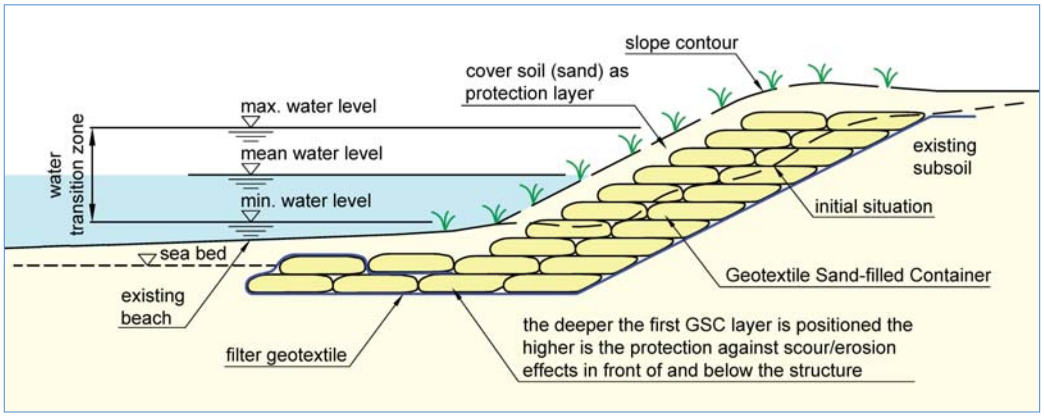

Figure 5 – Schematic cross-section of dune protection using Geotextile Sand Containers (GSCs) underground structure, covered with beach sand and planted with helm grass.

Figure 6 – Installation of Geotextile Sand Containers (GSCs) as a coastal protection measure in the dune core of the sandy beach, Ludmin, Germany.

highly suitable for reinforcing levees in soft soil areas. By using Finite Element Models (FEM), the relationship between forces, deformation and the interaction between soil and geosynthetics can provide detailed insights.

DRAINAGE SYSTEMS

With the rise of water levels outside the levees and subsidence in the polders, the hydraulic loads on flood defences are increasing. The increased hydraulic head will have a negative effect on the stability of flood defences. However, geosynthetic drainage systems can have a positive effect on hydraulic pressures. Installing levee drainage can be useful to avoid failure mechanisms such as macro and micro stability, by influencing the phreatic water line in the embankment.
Geosynthetic drainage mats consist of 3D structure composites, which must be pressure-stable under the given conditions. These drainage mats can be installed vertically (for example as toe drainage), horizontally (partly under the embankment core or berm) or on the slope.

Figure 7 – Installation of a reinforced High Performance Turf Reinforcement Mat (HPTRM) for slope protection.

Figure 8 – Installation of high strength geogrids as basal reinforcement below the flood defence at the Oder, Germany.

Conclusions

Climate change has significant effects on flood defences world wide. Sea level rise and extreme weather events have consequences for the safety, quality of life and sustainability of residential, industrial and agricultural areas. In the coming decades, extensive and costly operations to flood defences have to be initiated to keep local areas, larger regions or full countries safe and sustainable.

For the challenge of climate adaption, geosynthetics can contribute to adapt safe and resilient living areas for humanity. Geosynthetics can play a positive role in new or existing coastal and riverine flood defence systems: more sustainable, faster and/or cheaper construction. Making future-proof designs with geosynthetics in embankments is also a challenge. Levees must be adaptable to accommodate future levee reinforcements, in which applied geosynthetics in the levee should be manageable and not be an obstacle. Development of integrated concepts with geosynthetics will offer major potentials to advancing flood protection strategies.

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