Erosion Control with Geosynthetics

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GeSySo, CDR International en Admir Africa

Overview

– Introduction to erosion

– Conventional measures

– Geosynthetic elements for erosion protection

Bron: NGO mini lecture

- Waarom geokunststoffen in de waterbouw?
- Welke producten zijn er?
- Welke functies?
  - Erosie bescherming
  - Wapening
- Toepassingen
  - Filters
  - Zink- en kraagstukken
  - Geotextiele zandelementen

Waarom is het noodzakelijk?

- Het is noodzakelijk bij waterbouwkundige constructies en natuurlijke oevers waar water, zanddeeltjes kan verplaatsen.

- In het kort: waar zand en stromend water een interactie hebben.

De uitdagingen:

- Zeespiegel stijging
- Bodemdaling (door wateronttrekking): bv Jakarta, Tokyo, New York
- Klimaat, extreme belastingen (tsunami, cyclonen)

Jakarta: great Garuda

Erosion is a natural process

- "…erosion is the action of surface processes (such as water flow or wind) that remove soil, rock, or dissolved material from one location on the Earth's crust, and then transport it to another location…" (www.wikipedia.org)
- Focus of this presentation: erosion caused by water

Natural erosion protection: Dunes

Building with nature: Sand Engine

Man made Erosion

"While erosion is a natural process, human activities have increased by 10-40 times the rate at which erosion is occurring globally."

(www.wikipedia.org)

Cement/sugar bags are not geosynthetic elements for hydraulics!

No design and no concept in combination with…

…wrong materials!

Three Main Types of Erosion

Surface Erosion


Stream/Channel Erosion


Coastal Erosion

Surface Erosion (mainly caused by rain)

Rills leading to…

… the formation of gullies

Stream/Channel Erosion
(mainly caused by currents)

Currents (especially in outer river bends)…

…causing undercutting and progressive bank collapse

Coastal Erosion (mainly caused by waves)

Waves causing cliff formation and…

… progressive coastline retreat

Coastal Erosion (mainly caused by waves)

Cliff formation and coastline retreat can achieve substantial dimensions

Conventional counter measures for surface erosion

Vegetation

Conventional counter measures for streams

Rock (revetments)

Concrete Elements/Plates

Conventional counter measures at the coast

Rock (revetments)

Armor units

Conventional counter measures at the coast

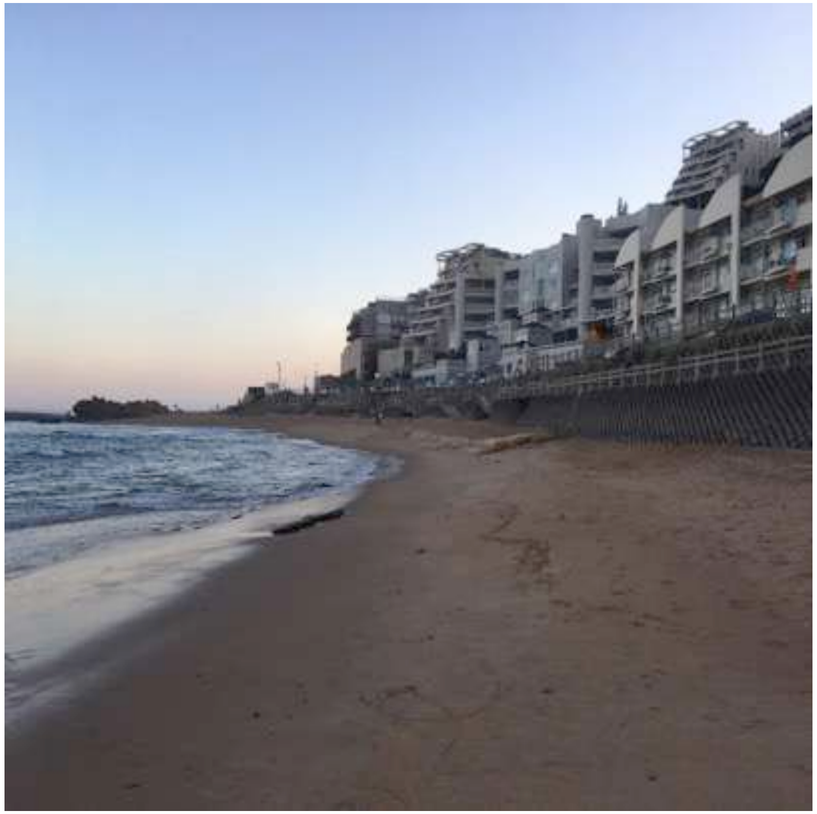
Asphalt (revetments)

Grouted rock (revetments)

Conventional structures to prevent or attenuate erosion

Seawalls made out of rock

Seawalls made out of blocks (concrete)



Conventional structures to prevent or attenuate erosion

Groins made out of rock

Groins as a combination out of wood and concrete

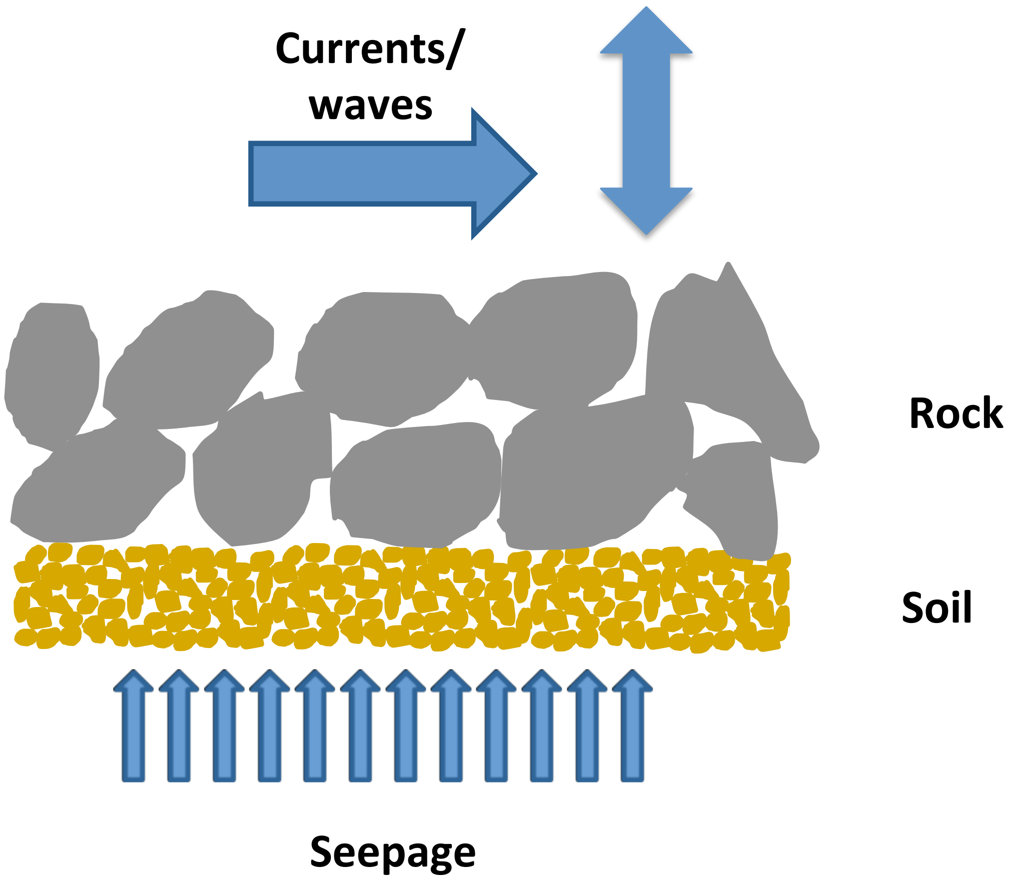
Conventional structures to prevent or attenuate erosion

Breakwaters made out of rock

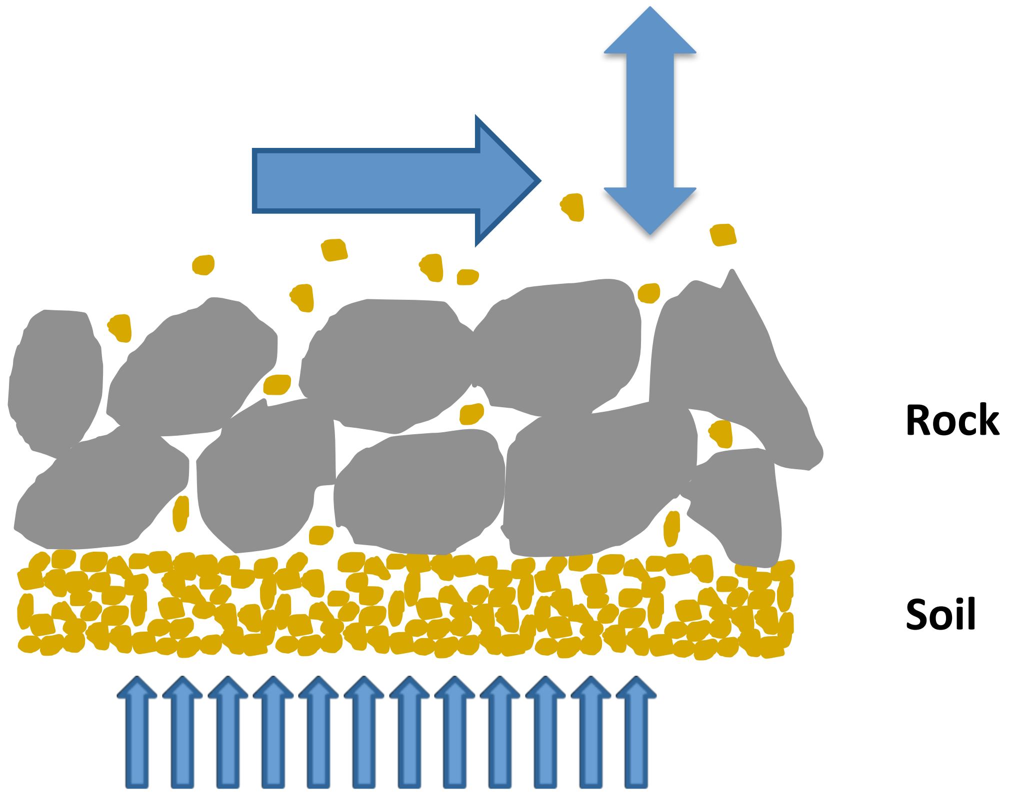
Breakwaters consisting of armor units

Where are the benefits of geosynthetics?

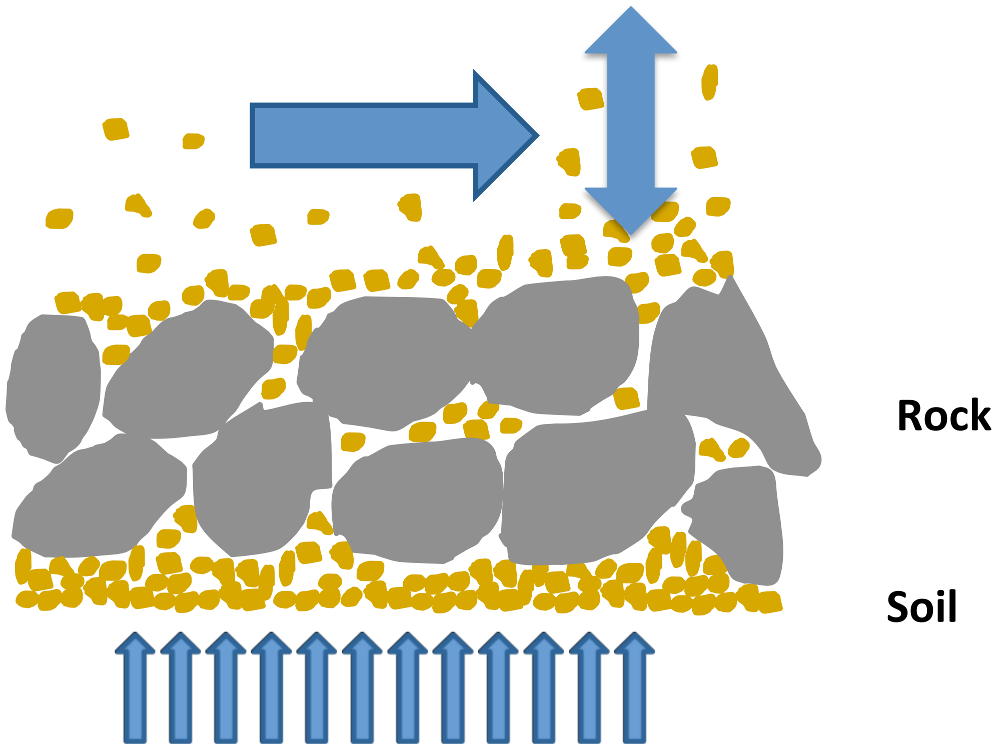
Erosion & Suffusion



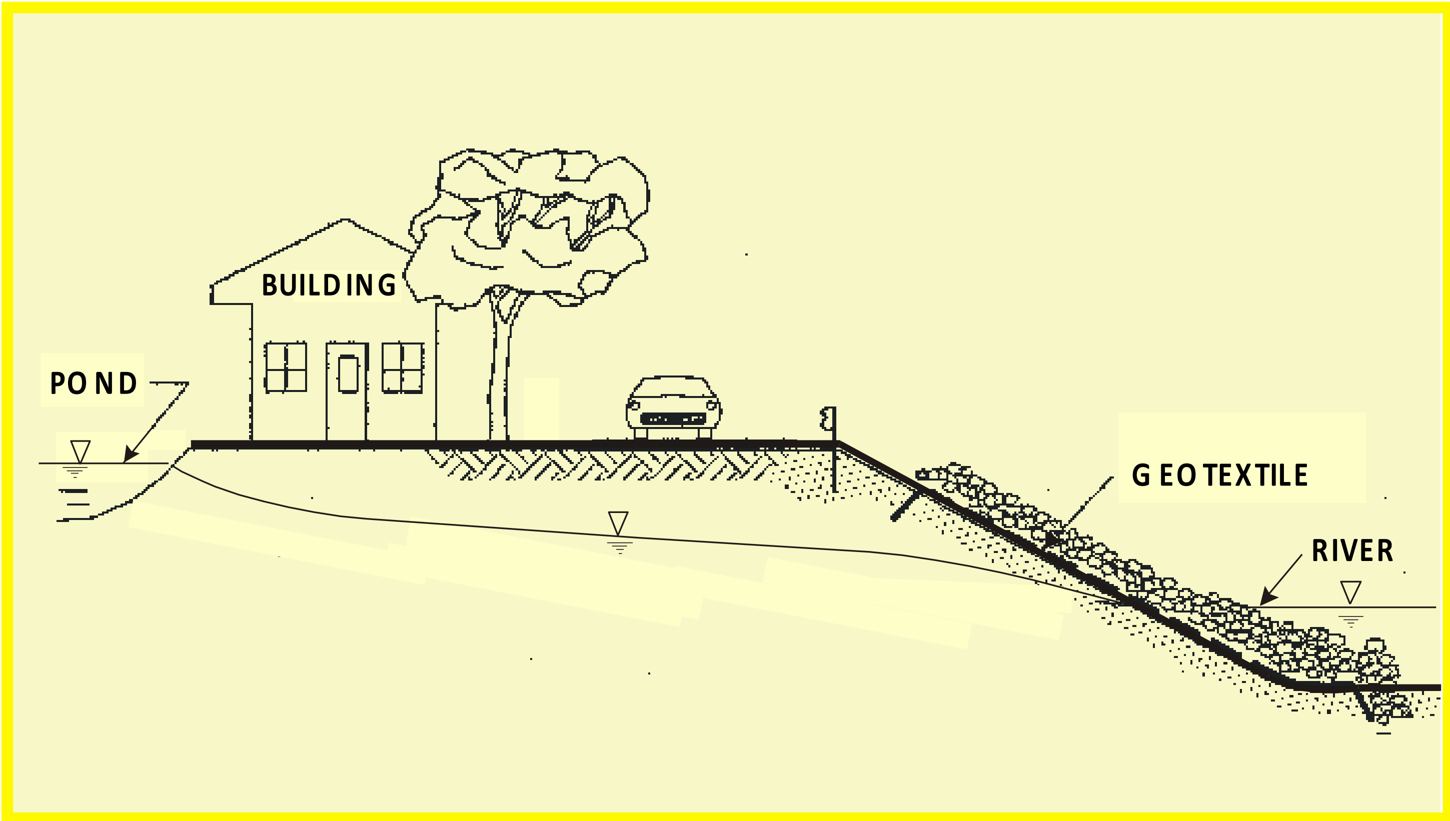
Erosion & Suffusion



Erosion & Suffusion



Filtertoepassingen



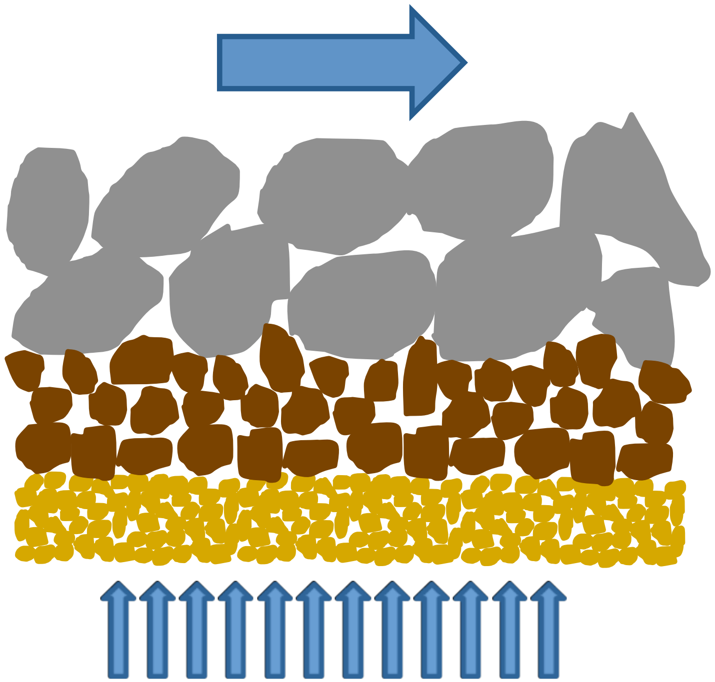
Erosion protectie (Pilarczyk, 2000)

Filter Design

Filter criterion for traditional granular filter layers according to TERZAGHI:

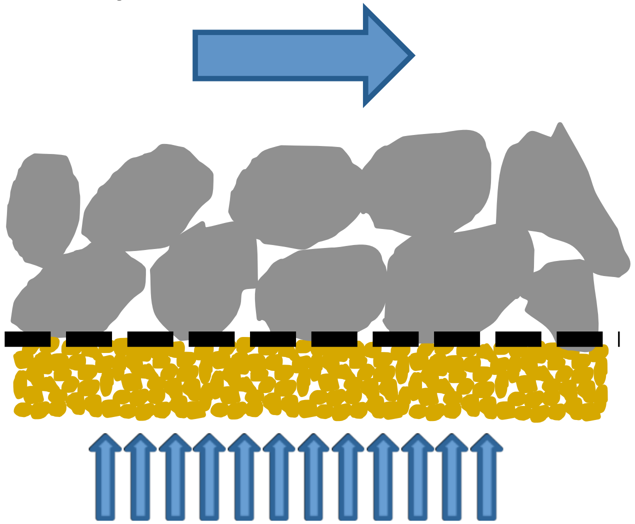
Retention criterion: $\frac{D_{15}}{d_{85}} < 4$

Permeability criterion: $\frac{D_{15}}{d_{15}} > 4$



Filter Design

Geotextile Filter (TERZAGHI's criterion adapted)



Retention criterion: $O_F < d_{85}$

Permeability criterion: $k_F \geq k_S$

O_F: Filter fabric opening size

d_{85}: Particle diameter of the soil to be filtered

k_F: Permeability of the geotextile filter

k_S: Permeability of the soil

Filter Stability

Free water flow

Hydraulically stable filter

Clogging

Hydraulically unstable filter

(clogged/blinded)

Filter Stability

Particle retention

Mechanically stable filter

Particle loss

Mechanically unstable filter

Filter Design: Two basic criteria for the selection of a proper geotextile filter

- Retention criterion: to prevent the migration of soil particles through the geotextile (and clogging)
- Permeability criterion: to ensure free flow of water through the geotextile (without clogging)
- An appropriate geotextile filter has to match both criteria in conjunction

Filter Design: Linking the soil properties with the geosynthetic characteristics

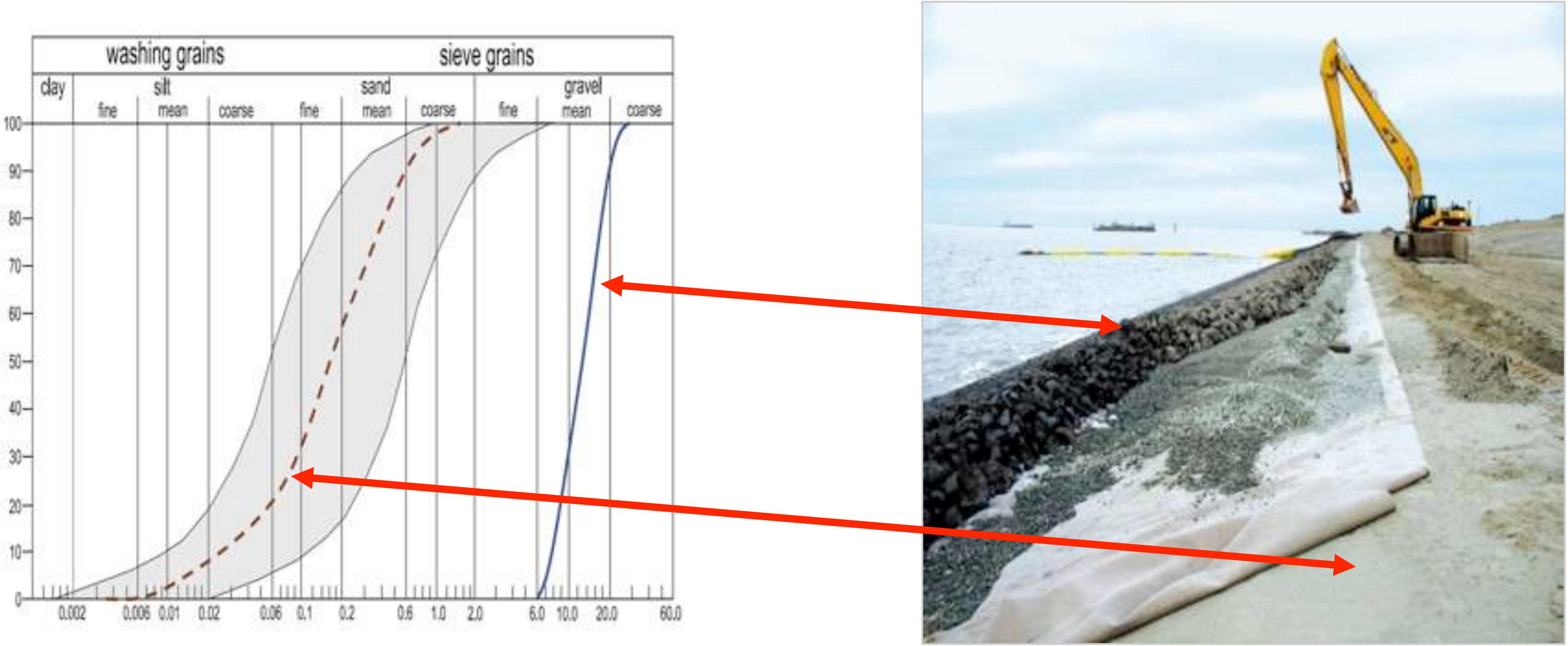
The soil is represented by:

- Particle size distribution (sieve size analysis)
- Indicative particle size (D_x)
- Coefficient of Uniformity (C_u)
- Permeability (k_n)
- Plasticity (I_p)

The geotextile is characterized by:

- Permeability k_n
- Pore Size (O_{90} or AOS (O_{95}), FOS)
- Robustness (installation damage; tensile strength & elongation)

Filter Design: Determination of design grading curves



The geotextile must be designed to be as permeable as possible with regard to the most permeable grading band (k_n), so that the finest non-cohesive granulation will just be restrained (O_{95} / O_{90}).

Filter Design: Robustness is an important issue

- Damage of the geosynthetic filter has to be prevented
- Critical moment: dropping of rock onto the geosynthetic
- Several tests available (recommended: BAW's dynamic perforation test)
- Impact can be compensated either by tensile strength or elongation of the geosynthetic material

Mainly used wovens or non-wovens (sometimes also composites)

Wovens

Non-Wovens

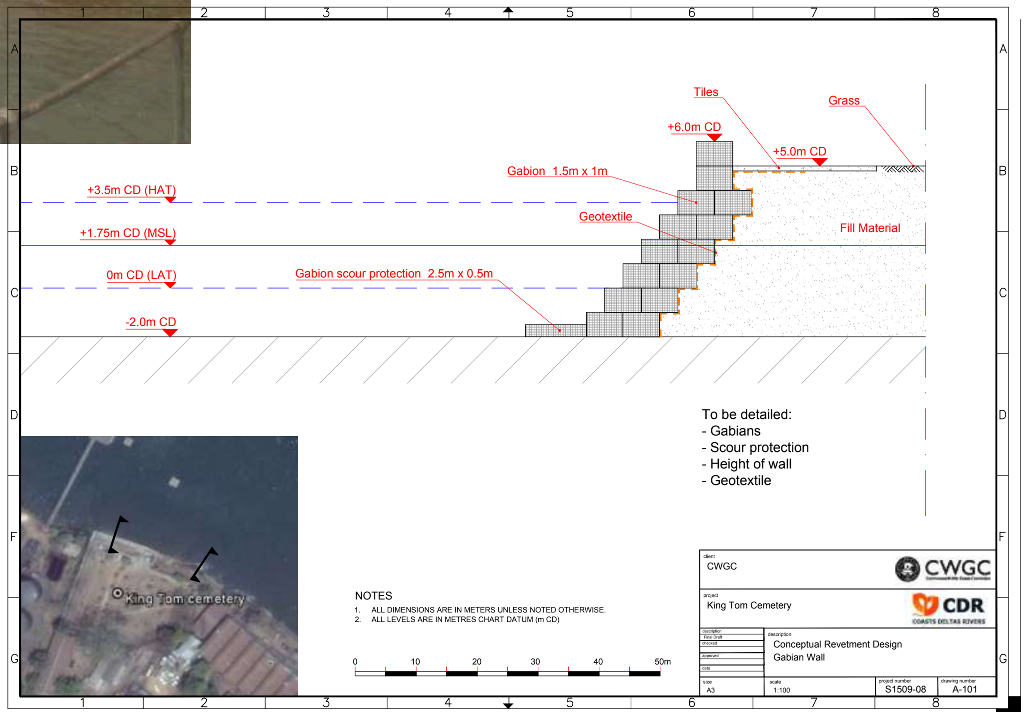
Available and applied handbooks/guidelines for designing geotextile filters (selection)

- DEPARTMENT OF THE ARMY – U.S. Army Corps of Engineers: Coastal Engineering Manual (EM 1110-2-1100), Part VI change 3, 28.11.2011
- CUR-report 174: Geokunststoffen in de waterbouw – Tweede herziene uitgave, Stichting CURNET Gouda, NL, 2009
- CUR: Ontwerprichtlijn Geotextilen onder steenbekleding, 2017
- CIRIA, CUR, CETMEF: The Rock Manual – The use of rock in hydraulic engineering (2nd edition), CIRIA C683, London, UK, 2007
- US Department of Transportation - Federal Highway Administration: „Geosynthetic design and Construction Guidelines", Publication No. FHWA HI-95-038, April 1998
- Canadian Foundation Engineering Manual, Canada, 2006
- Federal Waterway Engineering and Research Institute (BAW): Code of Practice: Use of Geotextile Filters on Waterways (MAG), Germany, 1993
- German Association for Water Economy, Waste Water and Waste (DWA): "Filtern mit Geokunststoffen" (Filtration with Geosynthetics; in translation), Germany, 2017

Geosynthetics allow for filter stable constructions

- Filter layer thickness can be substantially reduced (in comparison to mineral filters)
- Guaranteed continuous filter layer thickness
- Installation (especially under water) is facilitated
- Revetment stability is provided (erosion prevented)

Gabion seawall



Prevention of surface erosion

Prevention of surface erosion: Use of Erosion Control Mats

Reinforcement of the vegetation

Protection of the uncovered soil

Wide variety of erosion control mats

Source: http://
terrafixgeo.com

Source: https://
www.amleo.com

Source: https://
ca.brockwhite.com

Two different main types:

- **Natural (biodegradable) fibers (straw, coconut, etc.)**
- **Geosynthetic fibers (PP, PET, etc.)**

Source: https://
www.maccaferri.com

How do Erosion Control Mats work?

Mode of operation (two step process):

- The mat keeps the soil particles in place (un-vegetated condition)
- The mat reinforces the root system of the vegetation

Erosion control mats help to reduce the soil loss due to rain and surface run-off water

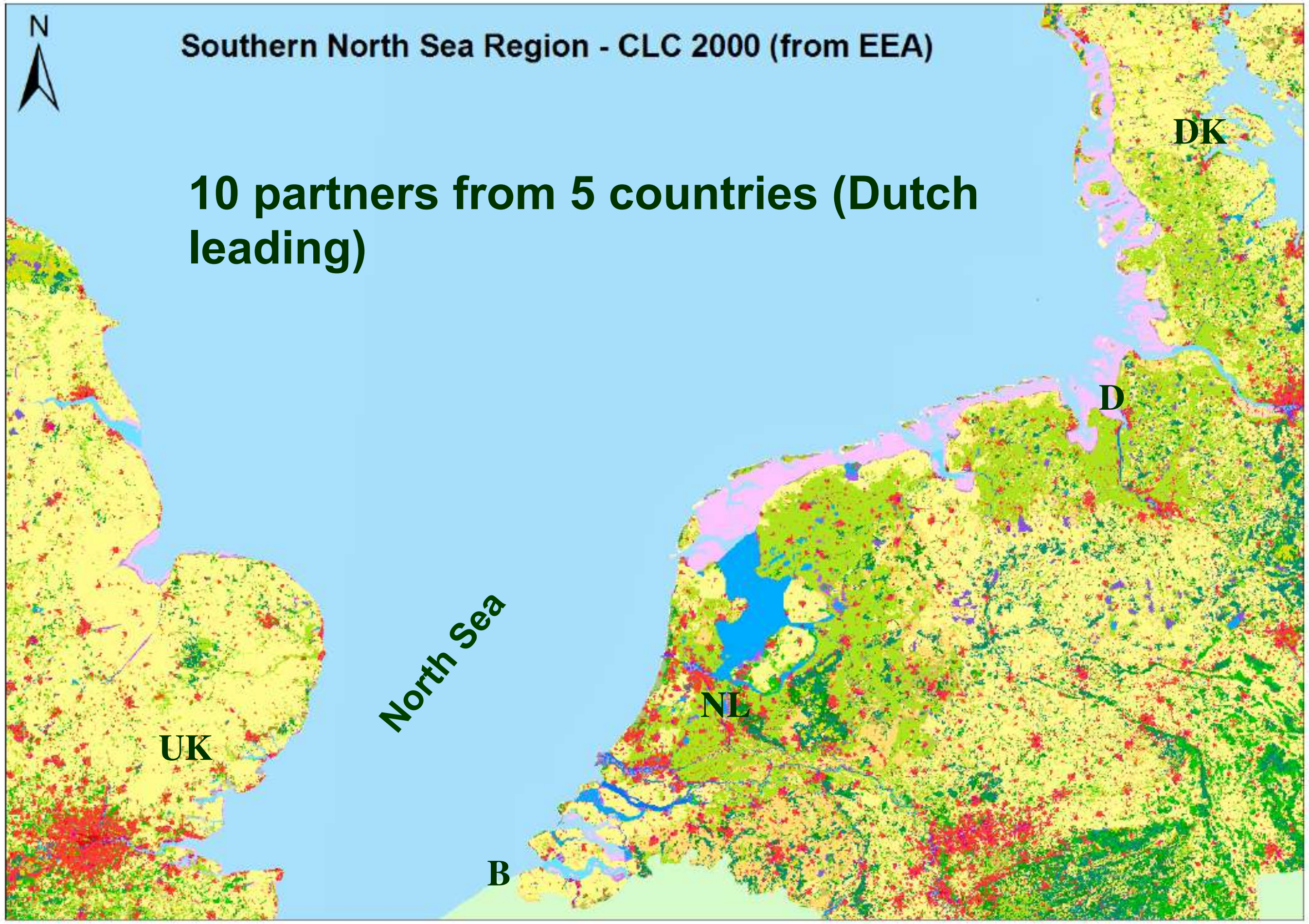
- Uncovered soil is protected (especially on slopes)
- Vegetation (root system) is reinforced
- Soil loss decrease due to the use of erosion control mats can be determined by the Revised Universal Soil Loss Equation (RUSLE)

(United States Department of Agriculture www.ars.usda.gov)

ComCoast

Combined functions in Coastal zones

:



Comcoast (2006)

Workpackage 3:
Development of Alternative Overtopping-Resistant Sea Defences

Phase 3:
Placement of Smart Grass Reinforcement at Test Sections Groningen Sea Dyke

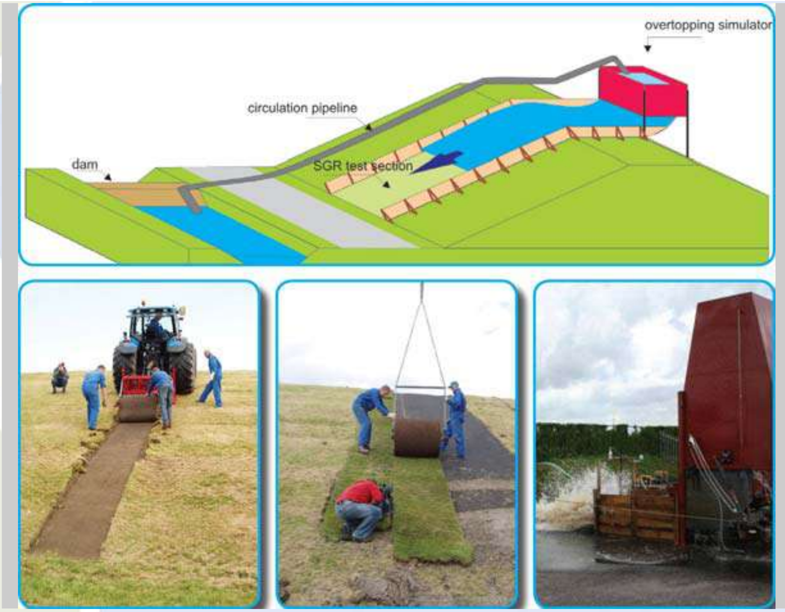


Figure 3-9: Replacement at the primary test section (without manual repositioning and removal of overlaps)

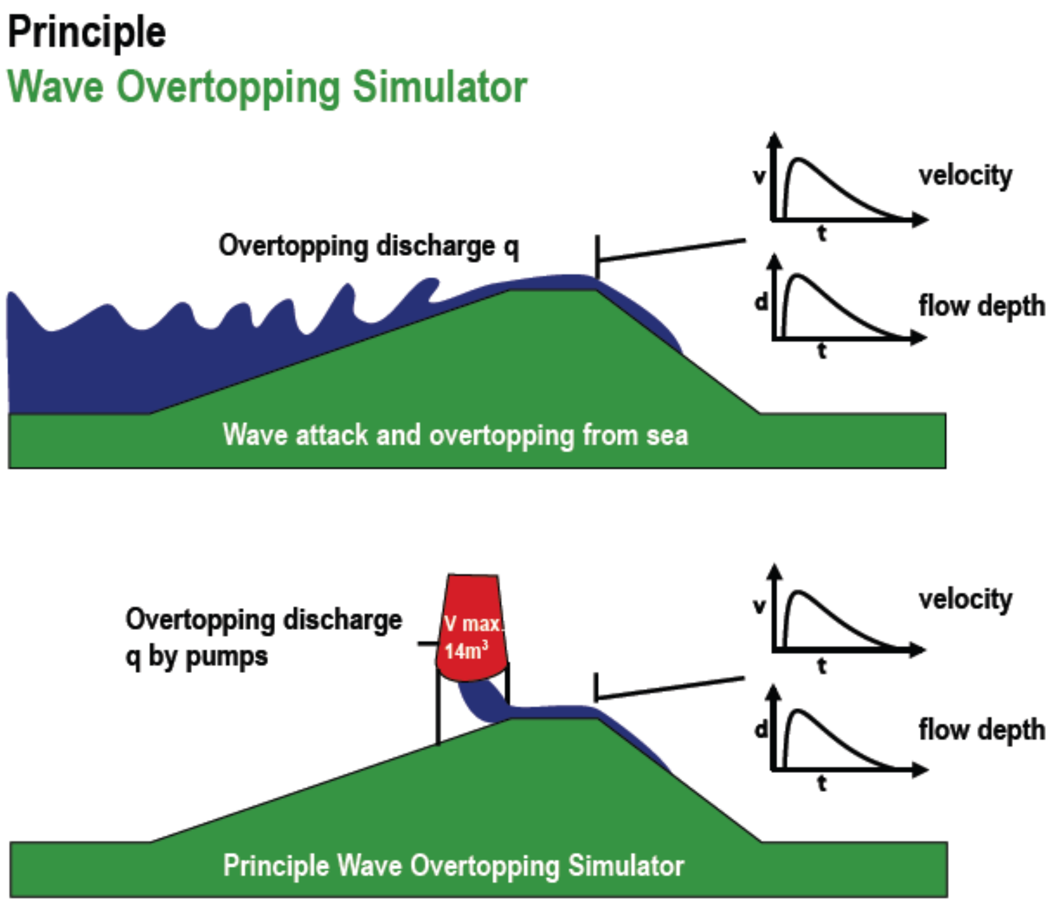


Figure 4-1: Principle of the reproduction of the overtopping wave tongues by the wave overtopping simulator

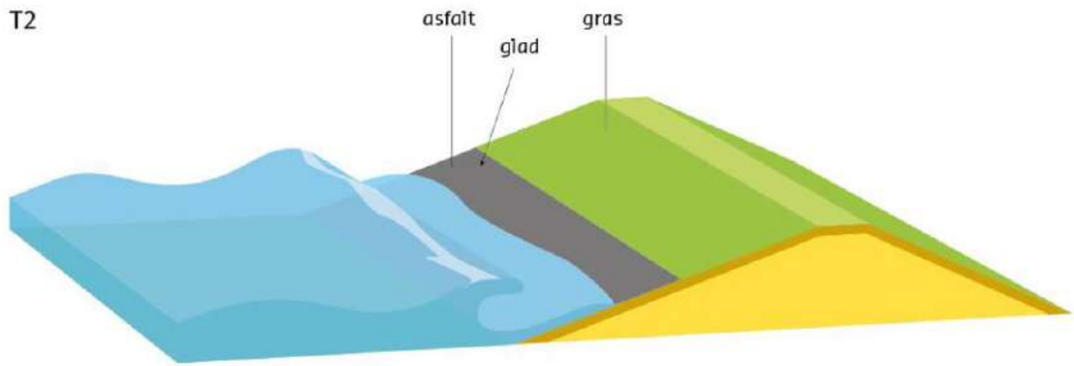
Figure 9-8: Start of the gully formation downstream of the damaged areas

Figure 9-9: Typical flow concentration at the gullies

Conclusions Wave overtopping test in Delfzijl:

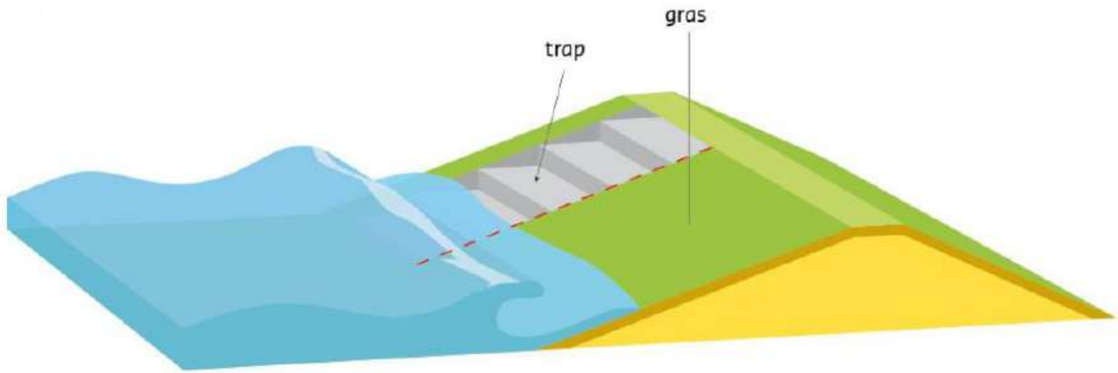
(1) Only clay on the slope
They had to stop during 10 l/m/s; already erosion by 1 l/m/s. This is a dike with a very good quality clay → sandy clay will give huge problems (60 % of the Dutch dikes)
(2) Natural grass slope
The condition was good. It performed well by 50 l/m/s.
When a hole was made erosion underneath the grass was great and the grass failed.
(3) Reinforced grass GRM
The condition of the grass was poor. It performed well by 50 l/m/s.
The 3D grass reinforcement was keeping the grass roots on its place.
When a hole was made the GRM kept the erosion locally and protected the underlaying clay

Deltares/RWS
Paul van Steeg
(2016)

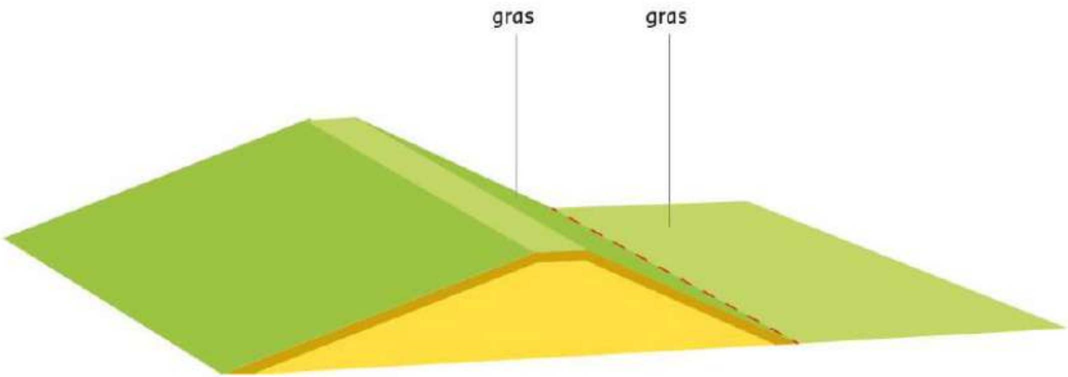


Figuur 1.1 Impressie van horizontale overgang (Type T2)

Focus op
mogelijke zwakke
punten graszoden
op buitentalud

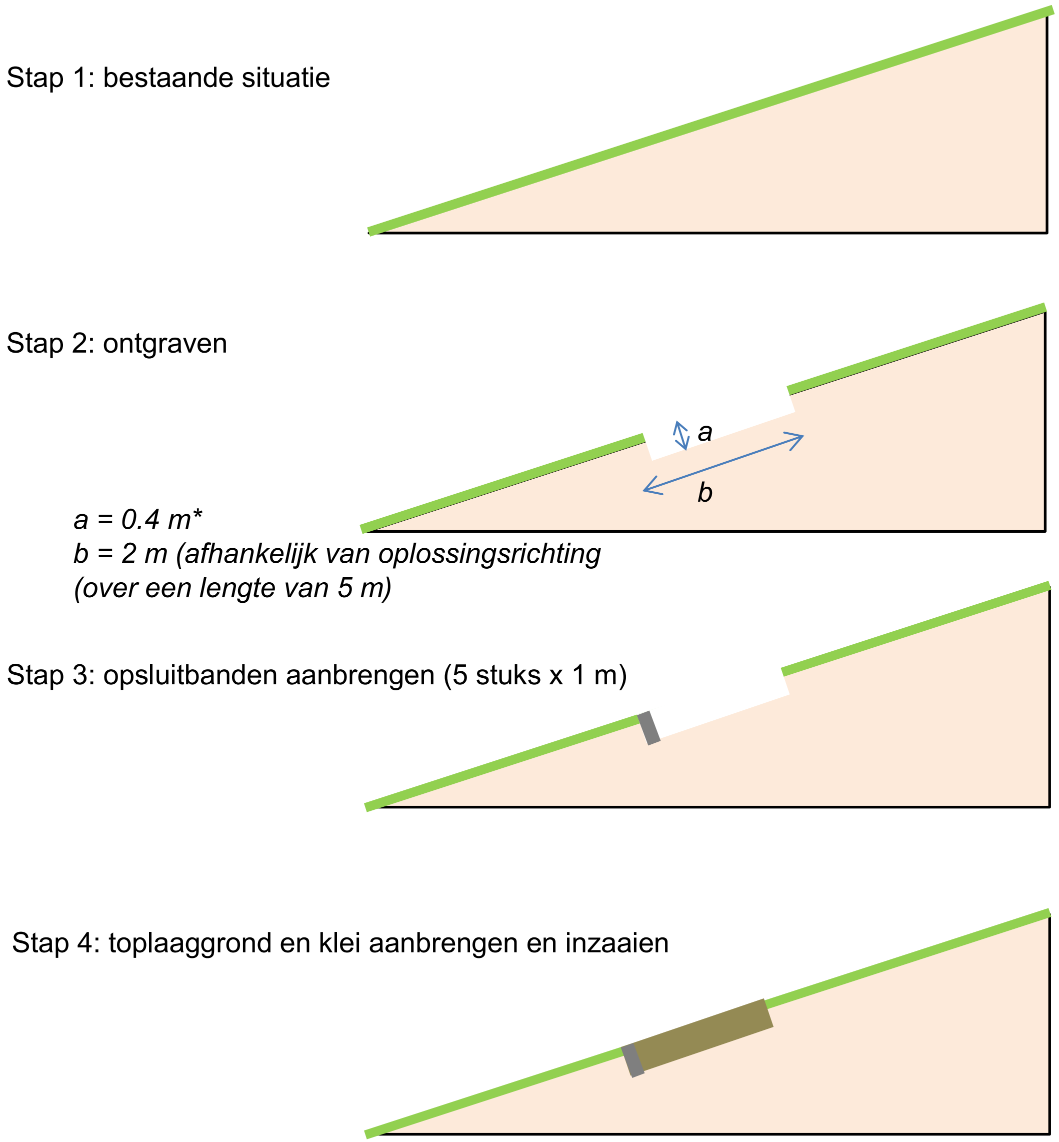


Figuur 1.2 Impressie van Type T8 (verticale overgang)



Figuur 1.3 Impressie van Type T6 (knik in het talud)

Figuur 4.3 Ontgraven van de testsecties tot een diepte van 20 cm. Op basis van de indruk die hier werd verkregen is besloten om de testsectie uit te graven tot een diepte van 40 cm.



Figuur 4.1 Schematische weergave van het maken van een overgang (type T2) zonder oplossingsrichting (referentiesectie)

Figuur 4.4 Situatie na volledig ontgraven van de klei

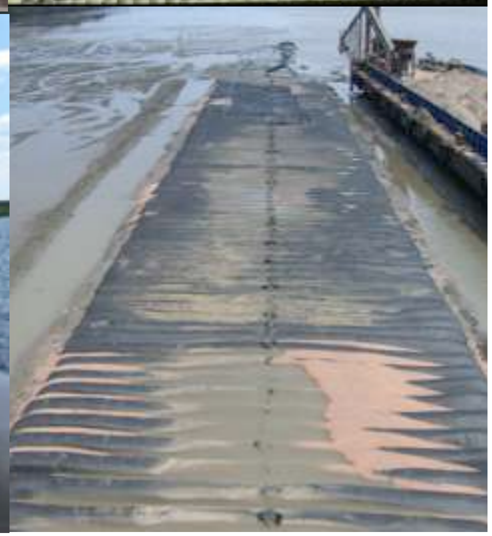
- 20 proefvakken/systemen
- Monitoring van graszode ontwikkeling
- Later testen (optioneel) met golfoploopsimulator of in deltagoot

Geosynthetic Elements: Definitions

Definition CUR 217			
Bags - 0.3 m³ to 10 m³	**Container** - 100 m³ to 600 m³	**Tubes** - Ø 0.5 m to 4.0 m; L = 25 m to 100 m	**Mats** - Two fabric layers internally connected

Definition PIANC Report nº 113			
Bags - 0.3 m³ to 5 m³	**Container** - 100 m³ to 600 m³	**Tubes** - Relatively long, circular geotextile sand filled elements, hydraulically filled	**Mats** - Flat sand filled elements, compartmentalized in cells, filled individually

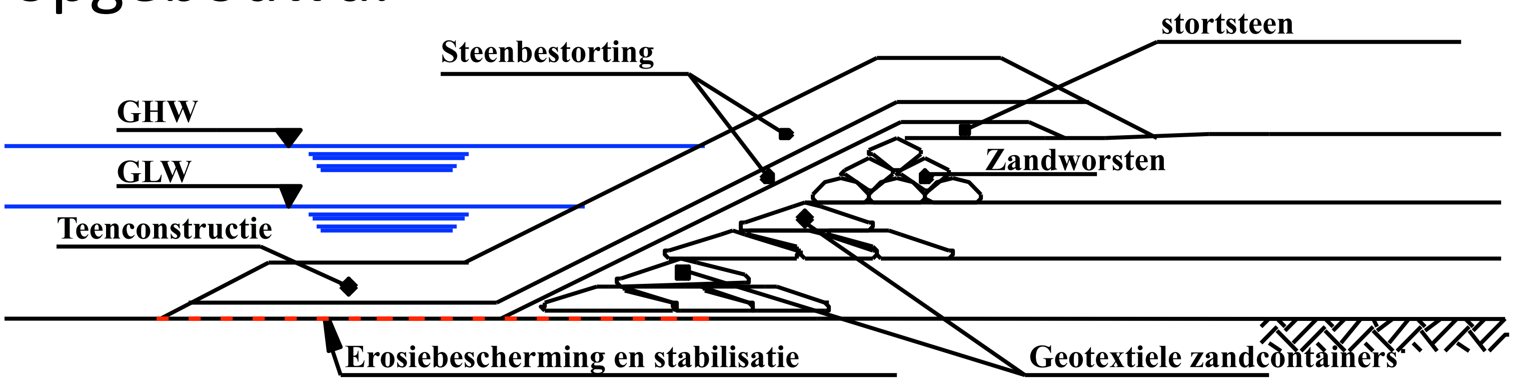
Geosynthetic Elements: Definitions

Bags	Container	Tubes	Mattresses
			
			

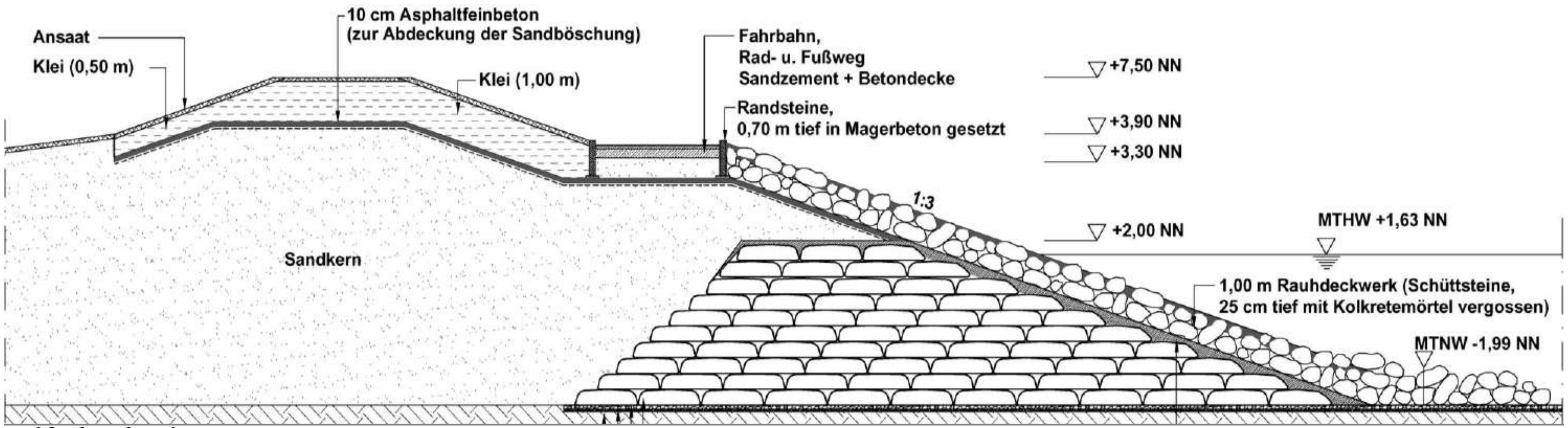
Source: https://
www.tencategeotube.com

Geotextiele zandelementen

- Geotextiele zandelementen kunnen daar worden toegepast waar weinig of geen stortsteen beschikbaar is. Vaak is er wel lokaal zand aanwezig.
- Met geotextiele zandelementen kunnen constructies, als dammen en dijken, worden opgebouwd.



Rüstersieler Watt, 1963: 1 m³ bags (Polyamid-woven)



What is a geosynthetic bag?

Filling by use of a funnel and a backhoe

Closing with a handheld sewing machine

Installation by a backhoe with a modified grab

- **Typically use of a non-woven (for flexibility and adaptation)**
- **When used as a construction element also application of wovens and composites**
- **Common volumes/dimensions: 0.3 to 2.5 m³**

Overview of a typical bag construction site

Geosynthetic bag applications

Revetments/Seawalls

Scour Protection

Breakwaters/Groins

Toe protection

Structure Core/Filter Layer

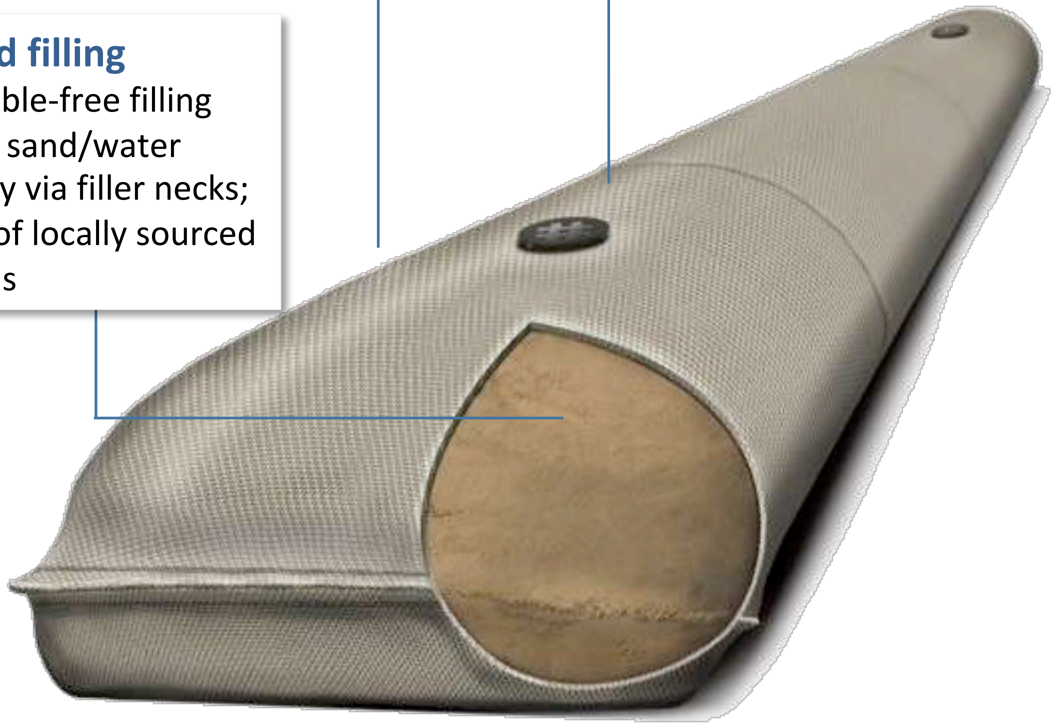
Dune reinforcement

What is a geosynthetic tube?

Geotextile tube
Prefabricated unit made from custom-developed and tested wovens or composites

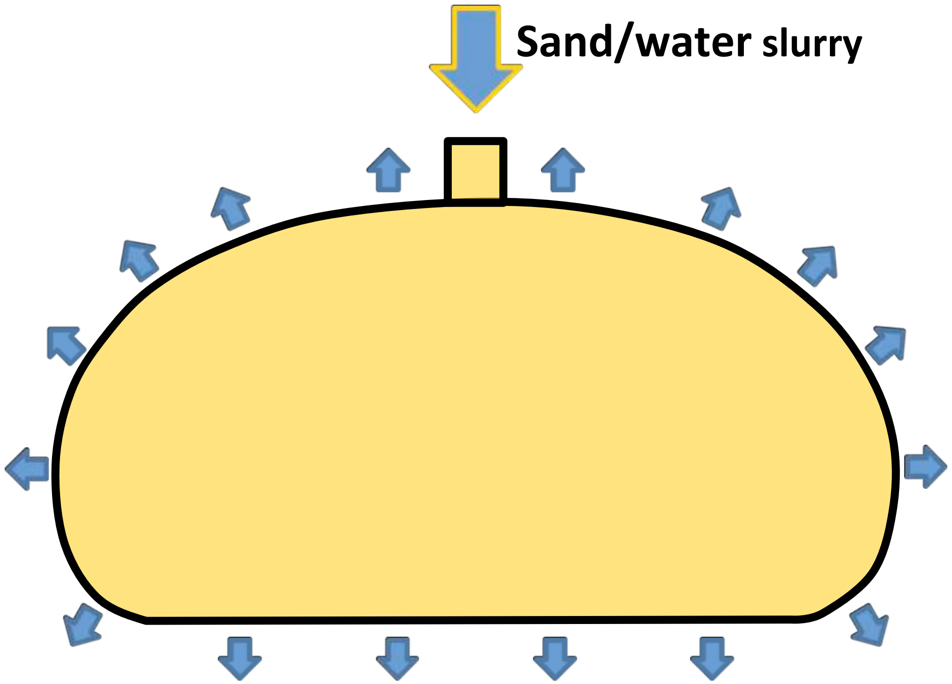
Filler neck
Rigid or flexible factory-fitted filling aid

Sand filling
Trouble-free filling with sand/water slurry via filler necks; use of locally sourced sands



What is a geosynthetic tube?

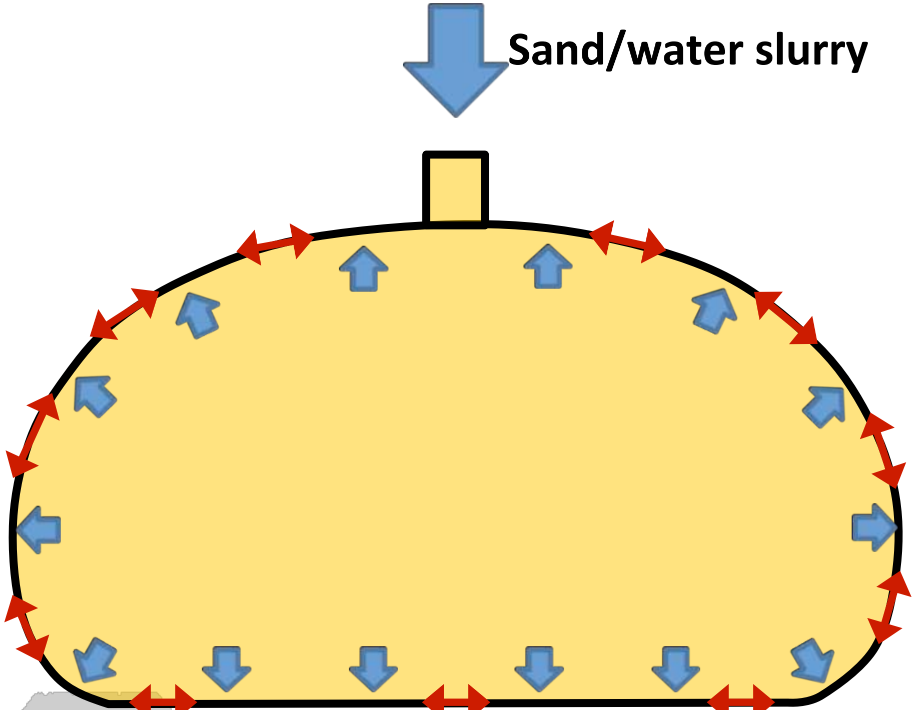
Water drains out – sand remains inside



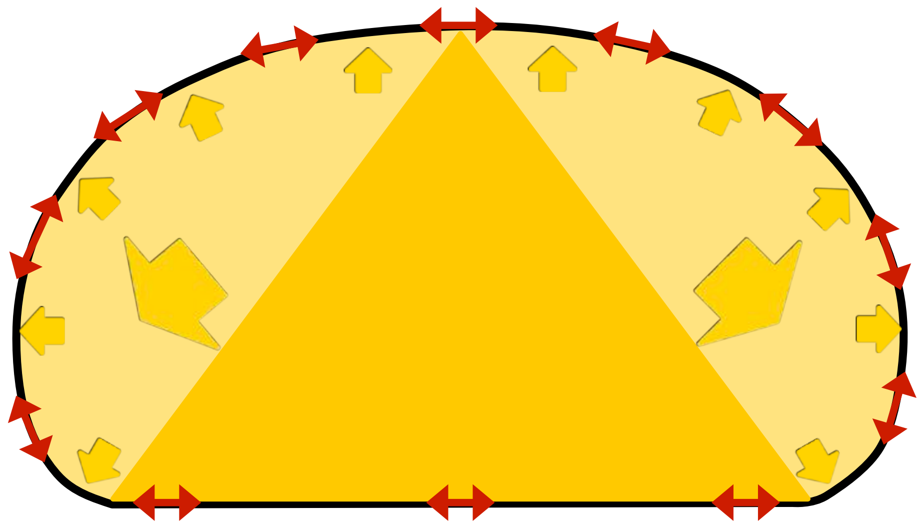
Installation in the dry

What is a geosynthetic tube? Ring tensile element!

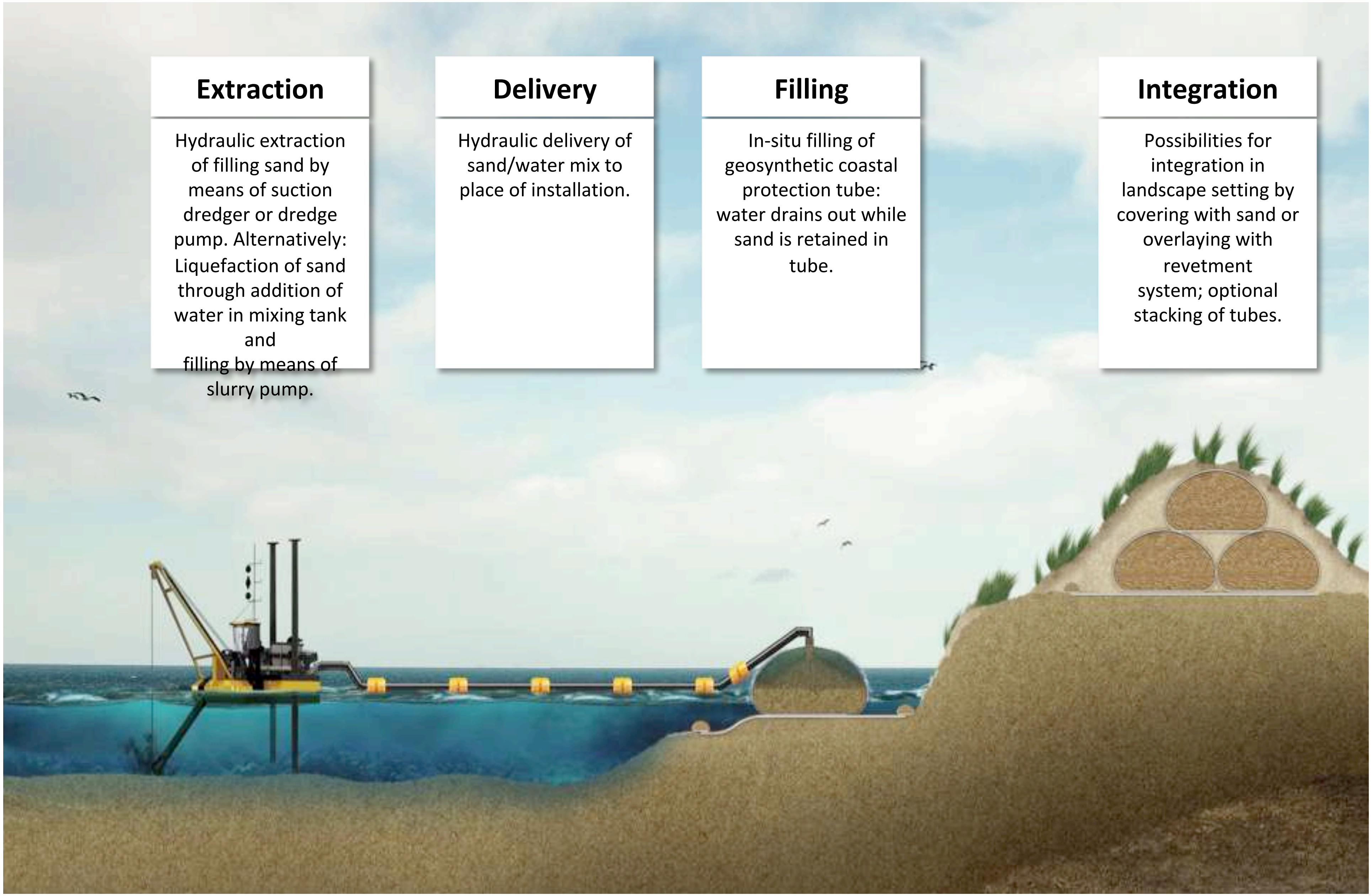
During filling: pumping pressure



After filling: “internal sand pressure” / ”confinement stress”

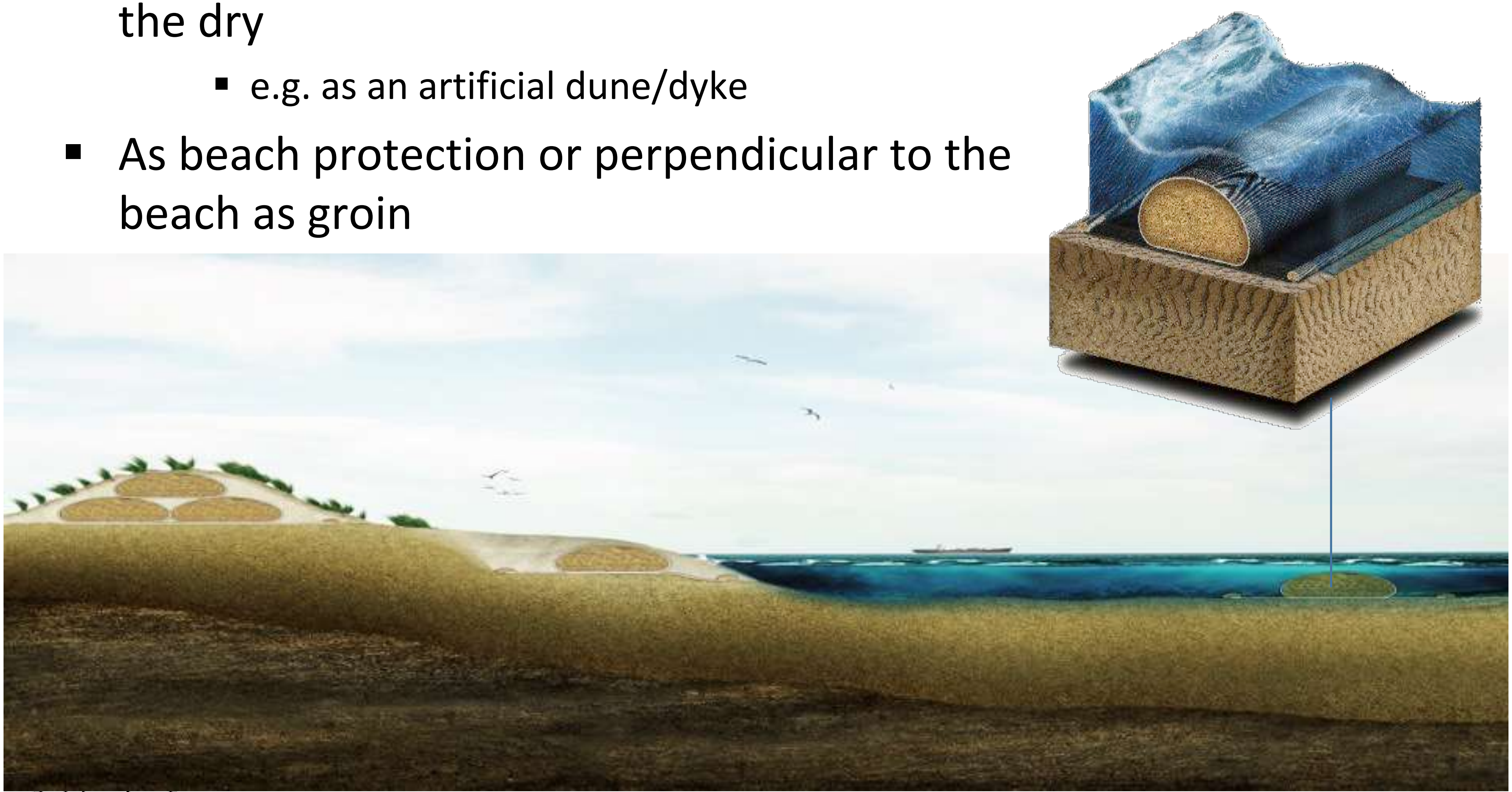


Geosynthetic tubes installation



Geosynthetic Tube Applications

- Protective element parallel to the coastline in the dry
  - e.g. as an artificial dune/dyke
- As beach protection or perpendicular to the beach as groin



Geosynthetic tube applications

Groin/breakwater core with rock

Submerged breakwater

Containment bund (with rock cover)

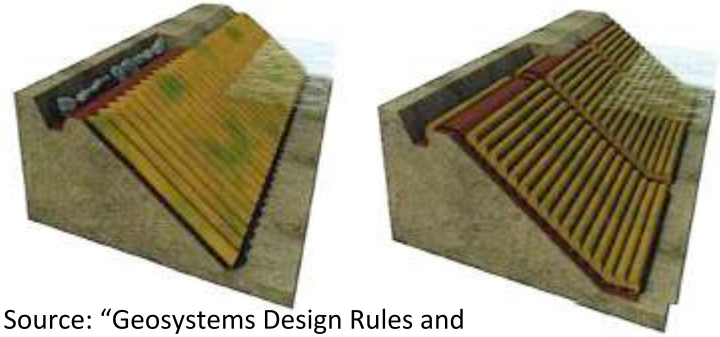
Groin

Breakwater

Dune reinforcement

Geosynthetic mattress types

Geosynthetic Sand (tubular)



Source: "Geosystems Design Rules and Applications"

Tubular mattress
Interwoven areas or stitches which provide the tubular shape of the mattress; mainly Polypropylene (PP)

Sand filling
Liquefied sand is filled (by pumping or gravity) into the mattress; sand remains inside, water drains out; easy filling via factory-fitted filling aids (e.g. filler necks)

Source: http://www.geosin.pt

Geosynthetic Concrete Mattresses

Geotextile formwork mattress
Polyethylene (PE) and Polyamide (PA) or Polyester (PET) double-woven fabric

Vertical ties/binders
Spacers; length adapted to project requirements (8 cm to 56 cm); maximize dimensional stability of mattress, thus ensuring constant concrete layer thickness

Interwoven areas/Filter points
Interwoven areas, which allow for the relief of excessive pore water pressures below the mattress; Can be greened above the water level

Concrete filling
Fluid concrete; easy filling via factory-fitted filling aids (e.g. filler necks)

Why concrete mattresses?

Technological and practical benefits

Inlet with a maximum inclination of 1:1,5 and an approx. length of 160 m for a max. discharge of 5 m³/s

- Coherent revetment
- Flexible system, which adapts to the underground
- High hydraulic resistance
- Installation on steep slopes possible
- Underwater installation common practice
- Robust and long lasting

Typical installation process for concrete mattresses

Why concrete mattresses?
Ecological and optical integration

Overflow section with concrete mattress during installation (HWS Furtherbach, AUT, 2015)

Overflow section after completion with greened sacrificial layer (HWS Furtherbach, AUT, 2015)

Concrete mattress as revetment

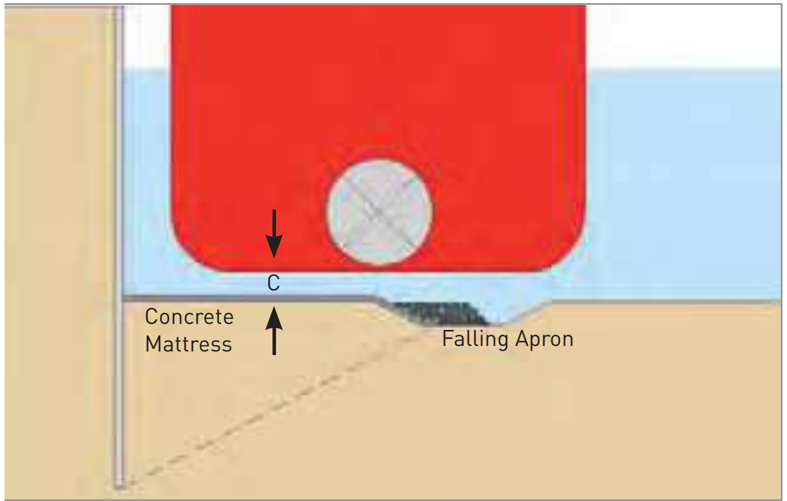





How do geosynthetic mattresses help to prevent erosion?

- Geosynthetic concrete mattresses are superior to flow loads (the system acts coherent, no stability proof of the single unit like for rock)
- Geosynthetic concrete mattresses can resist up to flow velocities of more than 12 m/s
- The main application for geosynthetic mattresses are as revetment





Case Histories: Cotonou; Belfast VT4 Ferry Berth
Technical Note: Berth Protection Using Concrete Mattress

Propeller Scour

Concrete mattress aprons are typically designed to resist propeller suction as they readily resist propeller flow. Design guides are used to estimate suction uplift forces on the bed. The principal parameters affecting suction and thus mattress thickness are:

- Propeller tip clearance to bed (C)
- Propeller diameter
- Engine power used on berth

Mattress edges often have a stone falling apron to protect against underscour.

NGO: Informatiebronnen

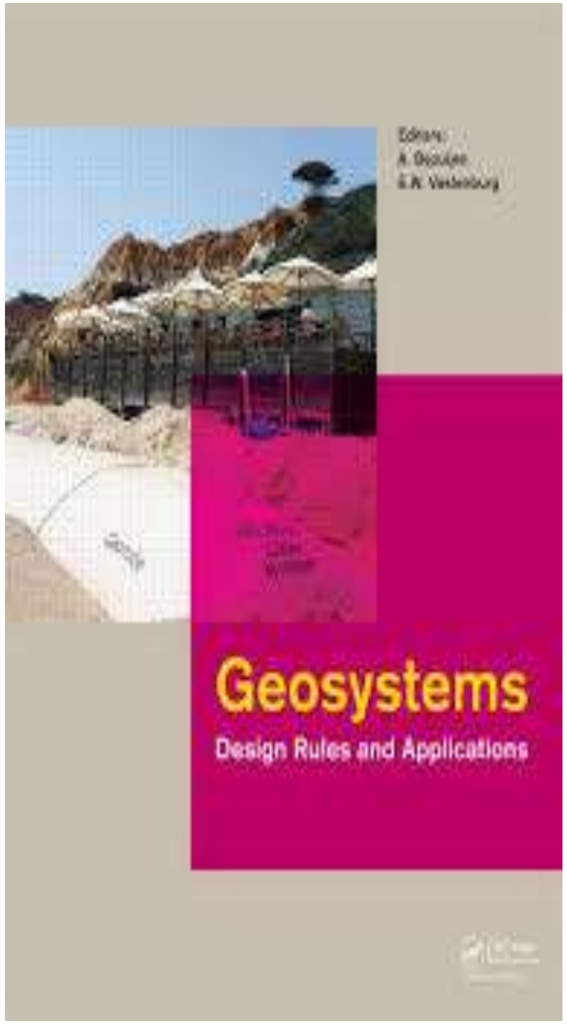
- Literatuur
  - CUR 174 Geotextielen in de waterbouw (nu Ontwerprichtlijn geotextielen onder steenbekleding, CROW, 2017)
  - CUR 186 Geokunststoffen en rivierdijkverbetering (??)
  - CUR 194 Vernieuwbare materialen in en rondom oevers (??)
  - CUR 214 Geotextiele zandelementen (niet meer leverbaar, nu CUR 217)
  - CUR aanbeveling 115: 2011 uitvoering van geokunststoffen in de waterbouw
  - CUR 217 ontwerpen met geotextiele zandelementen (2006)

- Indien u deze lecture zou willen gebruiken als lesmateriaal, kunt u contact opnemen met het secretariaat van de Nederlandse Geotextielorganisatie (NGO). Hier kunt u een beroep doen op een deskundige voor het geven van een gastcollege over dit onderwerp.
  tel. 030-6055800

  e-mail: mail@ngo.nl
- Voor verdere informatie, zie www.ngo.nl

Recommended guidelines for designing geosynthetic assembled elements (selection)

- Bezuijen, Vastenburg: Geosystems Design Rules and Applications (2013); English translation of the CUR 217 „Ontwerpen met geotextiele zandelementen“
- Concrete mattresses:
  - Krystian Pilarzcyk (2009): Design of Alternative Revetments
- Geosynthetic bags:
  - Darshana T. Dassanayake (2013): “Experimental and Numerical Modelling of the Hydraulic Stability of Geotextile Sand Containers (GSC) for Coastal Protection”
  - Juan Recio (2007): “Hydraulic stability of geotextile sand containers for coastal structures - effect of deformations and stability formulae”



Environmental soundness of geotextiles

- Only the use of geosynthetic elements allows the use of the naturally occurring sand on-site as filling/construction material (sustainable; less material transports)
- Fast colonization by the maritime flora & fauna (well accepted)
- Smooth installation procedure with very limited environmental impact
- Proven ecological compatibility

Source: http://trasomar.mc

Source: http://trasomar.mc

Conclusions

- Geosynthetics can substantially contribute to reduce the impact of erosion (or even stop and/or reverse the erosion process).
- Geosynthetic elements can replace conventional construction materials as well as whole structures.
- Geosynthetics have proven ecological compatibility.
- This presentation just provided a small insight of the overall potential of geosynthetics for erosion control. Some elements like silt fences, geosynthetic gabions, etc. even have not been mentioned.
- Bags and tubes are dominating for wave related applications whereas mattresses are superior for flow loads.
- The potential for geosynthetics in marine/coastal/hydraulic applications is huge!