The application of levee protecting geotextile coverings

This Guide is also a background document for the work instruction: "Applying a sand tight fabric with geogrid – ON THE OUTER LEVEE SLOPE – to prevent (further) erosion"

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1. Introduction

Introduction
The use of a geotextile covering to protect a levee against further erosion has been used for a long time. In early 2018, the Wiki Emergency Measures working group indicated the need for a working instruction for installing a levee protecting covering for a better understanding of the factors involved. In that year, a study was carried out in collaboration with TU Delft to explore the extent to which reinforcing measures for grass cover (protecting cover-layers) contribute to reducing the risk of flooding. Specific attention was paid to the reliability of the flood defense as well as the detection and installation of the measure. Although various useful conclusions and recommendations were provided, the working group subsequently opted for a more practical exploration.

This practical exploration started in 2018 with the aim of developing a cross-regional applicable working instruction. The starting point for this was the use of already existing working instructions from the former water authority Waterschap Groot Salland and of Waterschap Rivierenland. In addition, it was proposed to use a non-woven fabric equipped with a geogrid. Waterschap Drents Overijsselse Delta and other water authorities saw this as a highly promising protecting cover-layer.

From 2018 to present, work has been done to optimize the working instruction. At the end of 2020, the working group indicated that it would be good to now complete this (working towards a so-called version 1.0), but that it would also be good to write a guide that clearly presents the considerations and background relevant for use. This document concerns this guide - version 1.0.

Purpose & Scope of Document
Applying a working instruction during a crisis occurs under time pressure and stressful conditions. There is no time to make detailed assessments. A working instruction must therefore be simple, clear, and overview-based so that it can be used easily under stressful conditions. The fact that the working instruction reflects an overview makes it all the more important that sufficient insight into the factors and considerations involved in using the working instruction is obtained in advance. In the cold phase, there is enough time to understand these factors and considerations. The purpose of this guide is to set out these factors and considerations.

Although this guide has been specifically made for the working instruction "Applying a Sandtight Fabric with Geogrid – OUTSIDE THE LEVEE (to prevent (further) erosion)", a broader perspective will be given in various places. This also provides an overview. The latest insights from tests carried out in 2021 in the Living Lab Hedwige- and Prosperpolder will also be taken into account.

Like everything at Wiki Emergency Measures, this guide is also intended for water board employees who are involved in emergency measures. The guide is also intended for water management professionals and is meant to provide guidance on the application of a reinforcement measure for a levee to prevent erosion. The document aims to provide clear and concise information about the factors and considerations relevant to the use of the reinforcement measure in stressful conditions. The handbook provides a summary of the research and practical experience gathered so far, including the latest insights from trials conducted in the Hedwige and Prosper polders in 2021. The handbook is specific to the reinforcement measure "Application of a sand-tight fabric with geogrid - OUTSIDE THE LEVEE (to prevent erosion)" but will also provide a broader perspective in certain places.

From and for flood defense managers
Like everything else at Wiki Emergency Measures, this guide is also from and for flood defense managers. This guide was created with the help of the parties referred to in Chapter 7. All information, including this guide itself, can be found at www.stowa.nl/emergencyresponse.

We wish you a lot of reading pleasure and useful information!

2. Overview – types of protecting cover-layers

Overview "*Succesion*"
The so-called "*succesion*" is used when emergency measures are taken. This is shown on the website https://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Wiki_Noodmaatregelen_Waterkeringen_-_homepage and provides, so to speak, the "thinking framework". See also Figure 2.1 below.

Figure 2.1: The *succession* (1. Levee Anomalies & Damage patterns 2. Failure mechanisms 3. Emergency measures 4. designing & dimensioning 5. Execution)

If we further analyze this *succesion* around the subject of protecting layers, we see the following on a general level:

There are four failure mechanisms (orange), where the use of protecting cover-layers can be used. The protecting layer is generically described as a "protection against (further) erosion". To be able to recognize these, there are five distinctive damage patterns (red). Once we have defined a protecting layer as a solution, there are three very general handles (yellow) that are provided on how the protecting cover-layer can be dimensioned and what is needed for this.

The following figure shows this matrix of possibilities.

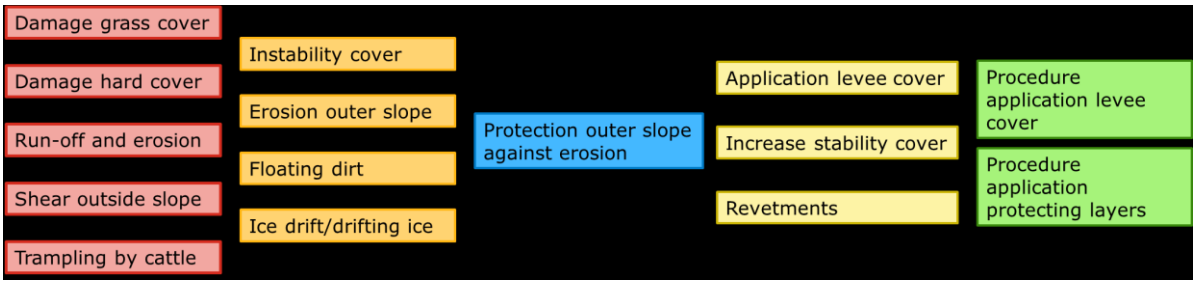


Figure 2.2: Development of options regarding the use of a protecting cover-layer for an outer slope (protection of outer slope against (further) erosion)

It should be noted that for the failure mechanisms described here, many of the accompanying damage patterns overlap. In other words, the damage pattern "Damage grass cover" reappears for different failure mechanisms.

Overview of protecting layers

Before we go into detail, it is good to realize what types of protecting layers are available. This depends on a number of factors:

- Location: outside or inside of the flood barrier
- Function: to prevent (further) erosion, to prevent water intrusion or to prevent outflow of sand/sediment
- Watertight versus sand tight

The following Figure 2.3 provides an overview.

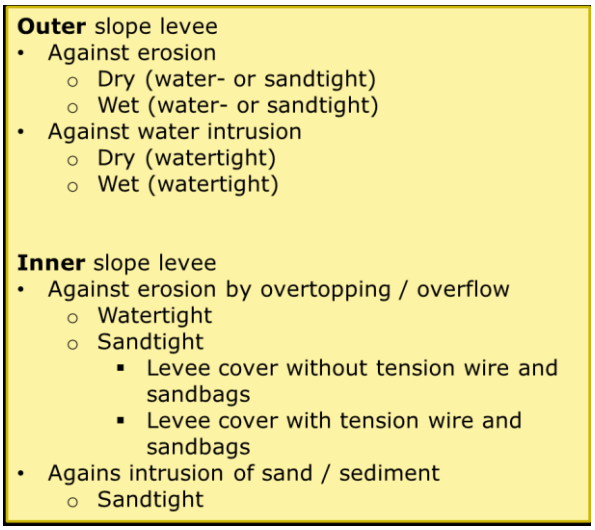


Figure 2.3: overview of types of protecting layers and levee covers

In this memorandum the emphasis is on: outside the levee, against (further) erosion, dry and sand-tight.

Protecting layers - what are the options?
General
For securing an outer levee against (further) erosion, there are different options: different types of fabrics can be used, you can use different types of staples/pegs and - depending on the damage pattern - some "repair" may have to take place beforehand. This last one means restoring the levee profile, for example, by filling the eroded spaces with clay or other material (for example, sandbags) to create as flat as possible surface.

In 2018, an inventory was taken within the working group regarding the clamps/levee covers used. This is shown in Annex A. In addition, during trials in the Living Lab Hedwige and Prosper polder (March 2021), a number of different fabrics and staples and pegs were also tested.

The following paragraphs will address this.

Type of fabric

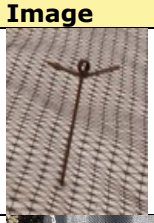
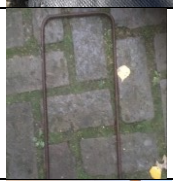
The following overview shows different fabrics and lists the main functions/properties and points of attention:

Fabric	**Functions / Characteristics (F/K) and Points of Attention (A)**
Tensar with geogrid	• F/K: sand-tight, highly permeable to water, at least 150 g/m², non-woven, largely lets sunlight through, easy to process, reusable (at least 3X) • A: is actually more of a road construction geotextile
Construction tarpaulin / Tarpaulin	• F/K: sand-tight, impermeable, PE, polyester, 100 – 250 g/m²; PVC 600g/m², reusable, with sturdy aluminum grommets for proper attachment of the tarpaulin • A: --
Agricultural sheet	• F/K: waterproof and sandproof tarpaulin, reusable • A: Prone to tearing, sequestered by sandbag ballasts
Reinforced Turf mat Gripple	• F/K: promotes faster and complete plant establishment with high flow resistance; three-dimensional matrix of thermally fused nylon monofilament, good anchor for root reinforcement • A: Can be installed on prepared seed areas or installed first and then sown and filled with soil.
Coconut mat	• F/K: biodegradable fibres

Fabric	Functions / Characteristics (F/K) and Points of Attention (A)
	• A: provides erosion protection against rain, wind and wave 'attack' as long as the grass is not yet able to do its job and will decay after a few months
Jute matte	• F/K: biodegradable fibers, staples are easy to stock; permeable to air and light; • A: Damaged more easily than geotextiles when exposed to tree trunks; reuse is possible, but it must dry well, the grass remains green.
PP80	• F/K: polypropylene; water impermeable 20 l/m²s; • tensile strength 56 kN /m; O_{90} = 275 µm • A: --
PE180	• F/K: polyethylene; water permeability moderate 100 l/m²s; tensile strength 50 kN /m; O_{90} = 210 µm • A: --
K400 Ecomat	• F/K: 0.9 x 10m; 4kg/sqm; thickness 40mm; fully expandable biaxially woven erosion protection mat made of biodegradable fibers in an open weave structure. Great water permeability; pens made of biodegradable polymer. • A: keep an overlap of 20 cm, 3 pins per running meter

Refer to the Living Lab Hedwige-Prosperpolder compaction research (Deltares report 11206793-009-ZWS-0002_v1.0) for findings on experiments with different fabrics and compactions in the Hedwige-Prosperpolder in 2021, which can be downloaded at www.wiki-noodmaatregelen.nl.

Confirmation type
Various confirmations are shown below, and the most important features and points of attention are mentioned:

Confirmation	Image	Features / Points of attention
Y – staples		• To hit with hammer, pull the eye to remove again. Removal is not very easy. • Length in the order of 50-80 cm • Reusable • Costs in the order of €7 each
T – staples		• Hit with hammer, pull T to remove again. Removal is difficult. • Length in the order of 45 cm • Reusable • Costs in the order of €5 each
U – staples		• To hit with hammer, pull U to remove again. Removal is not very easy. Staples can easily deform when driven in 5 – 80 cm • Reusable • Costs in the order of €10 each
Screw pegs Peggy Peg (left) / Wormi (right)		• Aluminum peg (length 30 cm). Easy to apply and remove with screw top, work quickly. Aluminum counter plate (150x150 mm, thickness 8 mm with a center hole of 21 mm) improves force transfer and distribution on the fabric. • Adapter (drill bit) can sometimes get caught on screw pegs. • Reusable • Costs in the order of € 10 resp. €18.50 each

Confirmation	Image	Features / Points of attention
Gripple Terra-Lock Pin TL-P3/4		• Galvanized steel peg. For softer/hard soil and heavier loads. With standard electric drill and specific installation adapter easy to install and remove, work quickly. Length = 300mm, wire diameter = 4mm; Counter plate (washer 50x50 mm) improves force transfer and distribution on the fabric. • stronger pulling force compared to traditional pins • Reusable • Cost estimate: in the order of €20 each

Again, reference is also made to the Bekrammingsonderzoek Living Lab Hedwige - Prosperpolder (Deltares report 11206793-009-ZWS-0002_v1.0), where the findings of tests with different fabrics and staples in the Hedwige and Prosperpolder in 2021 are presented.

Type of recovery that must take place in advance
The levee profile on which the covering is applied is preferably plane. This means that if the damage concerns a cavity or depression, it is recommended to fill it up first. It is desirable that the material can be deformed so that it backfills the cavity / depression as well as possible. It is obvious, for example – depending on the volume and what is available – to do this with clay or sandbags.

Cover choice
The remainder of this guide is based on Tensar Triax TX190L-G Geogrid and we translate this into the work instruction "Applying a sand-tight fabric with Geogrid – Outside the levee – to prevent (further) erosion".

It is hereby expressly stated that the basic principle is that this fabric is installed outside the levee as well as in dry conditions.

3. Process – from plan of attack to realization

Overview

Before applying a covering, it is important to have structure and insight into the steps to be followed for deploying this emergency measure. On the basis of the succession, as given in chapter 2, the diagram below can be given.

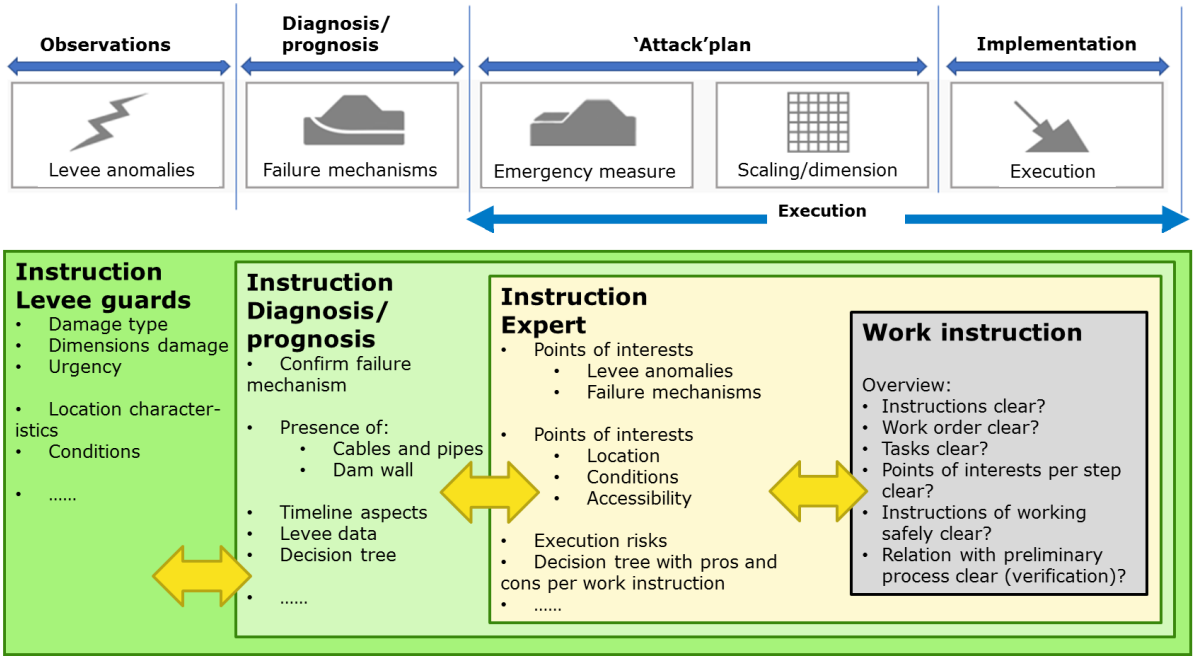


Figure 3.1: the succession at a glance

The following steps are to be distinguished:

- Preparation – either in the cold phase to ensure that you are able to apply a covering as an emergency measure;
- Observation – either you have dyke guards who can observe and register damage patterns;
- Diagnosis / Forecast – either you are able to determine the relevant failure mechanism(s) and their possible development over time;
- Plan of 'attack' – either on the basis of the location-specific circumstances you are able to make a plan to still guarantee the safety of the barrier by means of a covering;
- Realization of the measure – or on the basis of a work instruction you are able to steer the implementation in the right direction.

You can go into more detail for each step. This concerns, for example, the use of aids and "sub-steps" can also be named. This is discussed in outline in the following table.

PHASE	PURPOSE / POINTS OF CONSIDERATION / TOOLS
Preparation	Target: - State of maintenance: you have the necessary materials - Employees (including contractor if applicable) are instructed, trained and exercised; - Plans & work instructions: for example, have a plan of attack and work instructions.
	Points of attention: - Overview of what is located where and in what quantities and in what condition - Knowledge of the various considerations and points of attention that play a role (including this guide); - Make sure that everything is documented, so that duty of care can be demonstrated in a traceable manner
	Tools: - N/A
Observation	Target:

PHASE	PURPOSE / POINTS OF CONSIDERATION / TOOLS
	- Timely observation of any damage and recording this
	Points of attention: - Determine type, size and urgency; - Attention to site-specific conditions
	Tools: - Damage registration form; damage registration app (see https://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Wiki_Noodmaatregelen_Waterkeringen_-_homepage)
Diagnosis / Forecast	Target: - Determining the cause (= occurring failure mechanism) of the damage pattern and possible consequences
	Points of attention: - Insight into levee properties (geometry, structure, subsoil) and e.g. test results - Attention to cables & pipes and the presence of structures - Identifying risks
	Tools: - The so-called "8-question analysis" (see https://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Wiki_Noodmaatregelen_Waterkeringen_-_homepage under Guides & Work Instructions)
plan of attack	Target: - Come up with a well-considered and feasible plan for implementation, including attention to requirements, phasing, division of roles and points of attention.
	Points of attention: - Recognizing uncertainties and risks and translating them into feasible mitigating measures; - Attention to available and required time; - Attention to a practical approach, ensure that optimizations are feasible; - Weighing up alternatives and choosing a feasible approach, also paying attention to logistics (including traffic measures); - Clear communication, including coordination with third parties where necessary (including municipality, security region and possibly owners).
	Tools: - Plan of attack (see https://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Wiki_Noodmaatregelen_Waterkeringen_-_homepage)
Realization	Target: - A clear work instruction for applying a cover
	Points of attention, for the next steps: - Step 1: reconfirm plan of attack - Step 2: fencing off & set up work area, including supply route - Step 3: supply materials - Step 4: apply and finish materials - Step 5: check & feedback
	Tools: - Work instructions are required for this (see chapter 4).

Plan of attack
As indicated above, the aim of the plan of attack is to reach a well-considered and feasible plan for implementation, including attention to requirements, phasing, division of roles and points of attention. It is important here to first confirm the failure mechanism and associated suitable emergency measure at the start of this step in the succession. If this is clear, the work instruction can in principle also be selected.

In the following, the most important considerations for the plan of attack for the application of a covering are presented.

- It is advisable to prepare a trailer with all the necessary material. This way you can move out quickly.
- Attention is needed for the location where the covering is applied, how close can you get with the trailer, how far to the location and what is needed for that? Also pay attention to the supply route: are bottlenecks to be expected here?
- Don't forget PPE, including, for example, rain pants and a jacket!
- Pre-fill erosion holes (with sandbags) so that a relatively plane surface is obtained. This requires an estimate of the volume to be filled as well as the properties (for example crack or pit). This must be explicitly indicated to the executing team because the work instruction itself assumes a plane surface.
- Preferably adjust the dimensions of the roll to the required length in advance as well as possible. However, make sure there is rather too much than too little.
- State possible risks for the implementation (e.g. cables and pipelines, weather, site conditions).
- Determining the type of barrier and properties of the barrier so that you can determine which pins are most suitable. The number of clamps also determines the number of pins required.
- Should the protection of the site or the diversion of third parties (e.g. passers-by) be taken into account? Make sure that the necessary material is loaded for this.
- Determine requirements and check whether they are also available. Improvise, if necessary, for example by bringing a second roll or using different pens.
- Determine available and required time.
- Finally, reconfirm which work instruction should be used.

Fill it in as best you can and use it as a checklist, as it were. See also Figure 3.2.

Execution emergency measure	
Emergency measure to be carried out	
Work instruction to be applied *Which work instructions are used (this can also help you determine the required capacity).*	
Required capacity *Number of people*	
Required material *(sand, sandbags etc.)*	
Required for transport *(Vans etc.)*	
Required equipment	
Required traffic measures *(road management/rental/own)*	
Required of third parties - *Capacity* - *Equipment*	
Risks - Which risks should be taken into account? - Danger of collision due to traffic - Risk of falling - Danger from working under a crane	

Description of the work instructions
Describe here the working order and instructions per step:
* Collecting equipment Who is doing what?
* Availability equipment What type of equipment is available and what should be rented?
* Accesbility of the working location How should the location be approached?
* Wat is the working order of the needed emergency measures on site? Name the actions and who does what?

Figure 3.2: Template plan of 'attack

The plan of attack is then the starting point for the next step, the realization. This will be described in the next chapter.

4. Explanation and background work instruction

Explanation

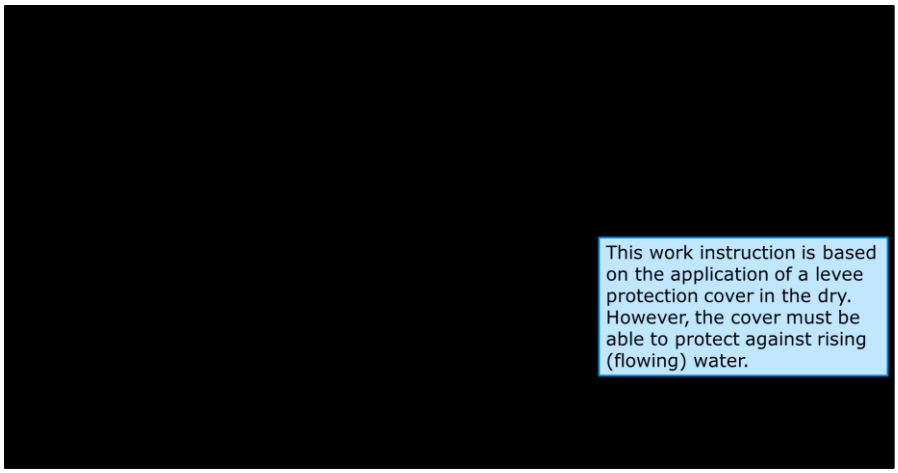
The work instructions are presented page by page in the following paragraphs. If necessary, specific points for attention or underlying considerations are presented per page in order to gain a better understanding of the page in question. This is version 1.1.

Title page

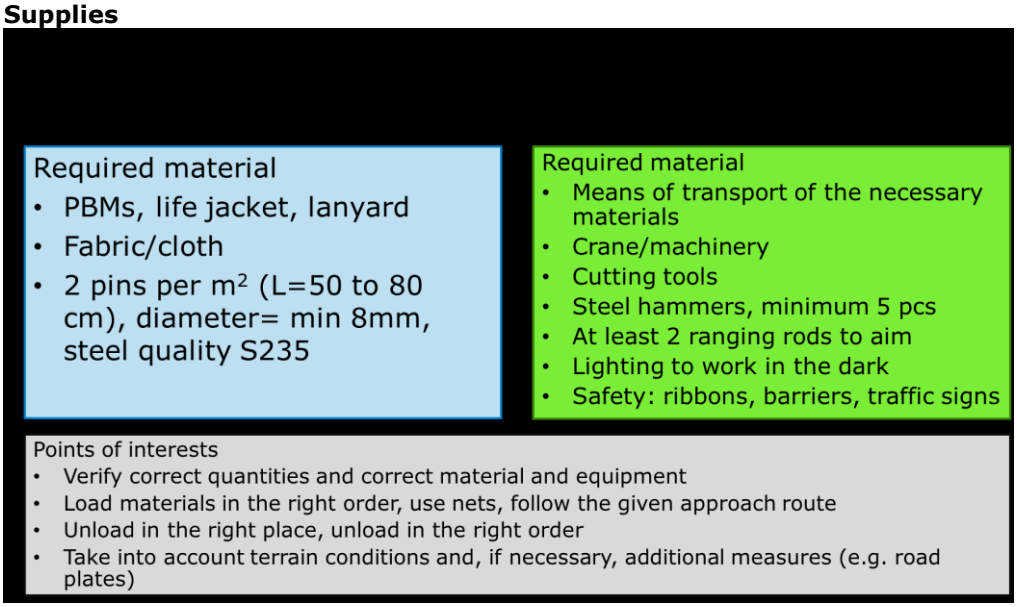
Points of attention and considerations:

- The manager can place his logo at the indicated place on the work instructions. This immediately indicates that the organization has confidence in the instruction.
- Have one person in charge.

Index



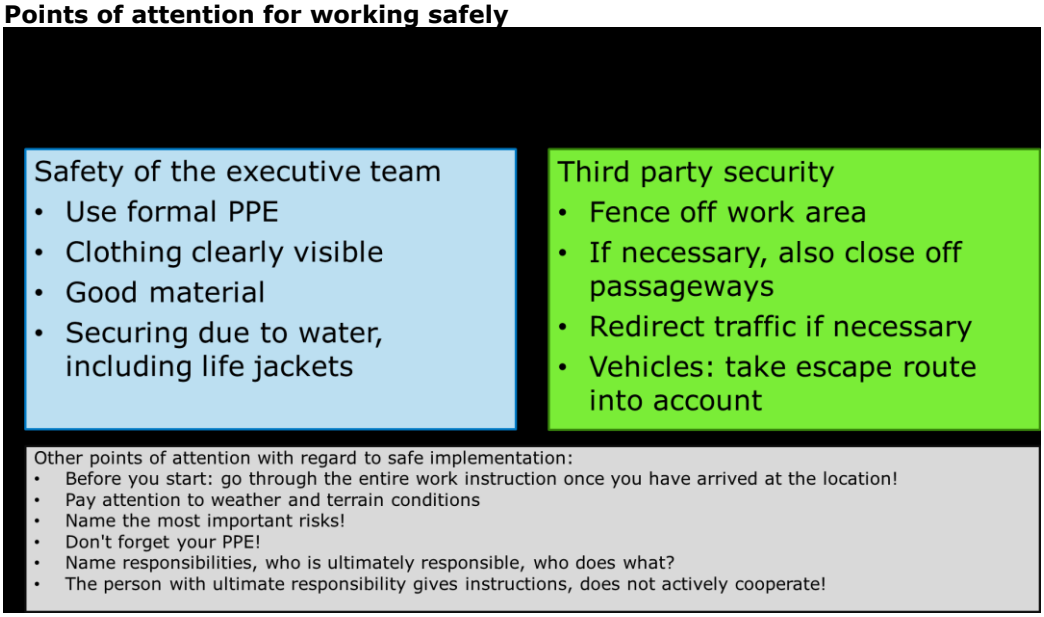
Supplies



Points of attention and considerations:

- The work instructions contain only generic information. So, location-specific and damage-specific aspects must be verified separately and must be in line with the plan of attack.
- Going through quantities is also recommended once you have arrived on location, as this provides an overview.

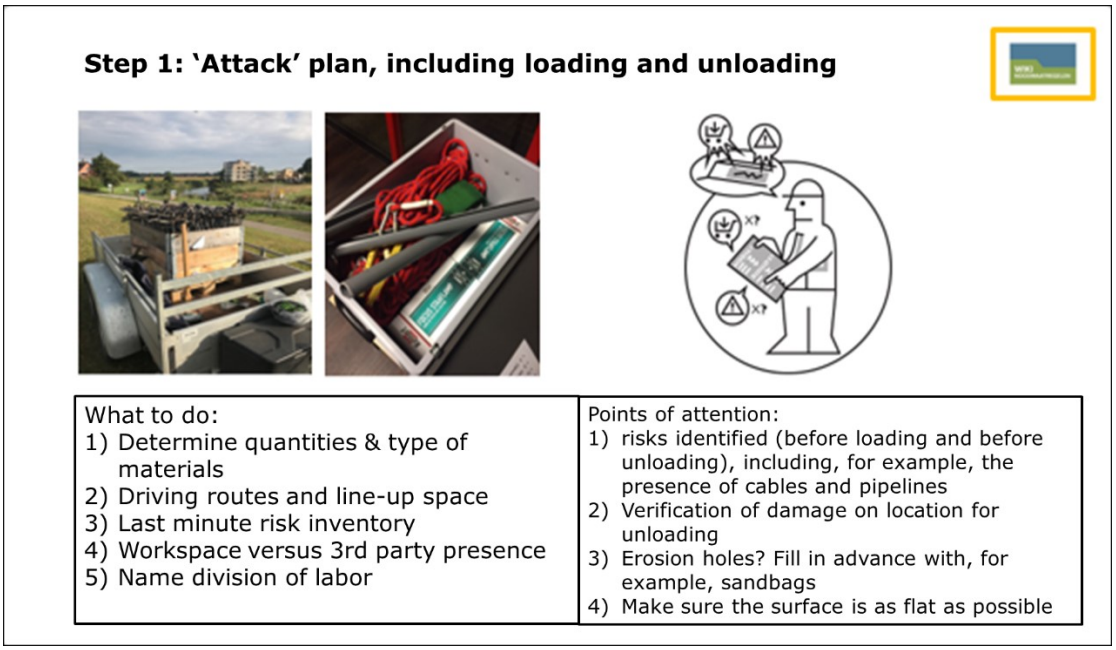
Points of attention for working safely



Points of attention and considerations:

- As stated earlier, have one person in charge!
- The idea is that when you arrive on location, you first go through the work instruction with the team before going through it page by page. This gives everyone an overview and insight into what needs to be done. This also helps when subsequently identifying the risks.

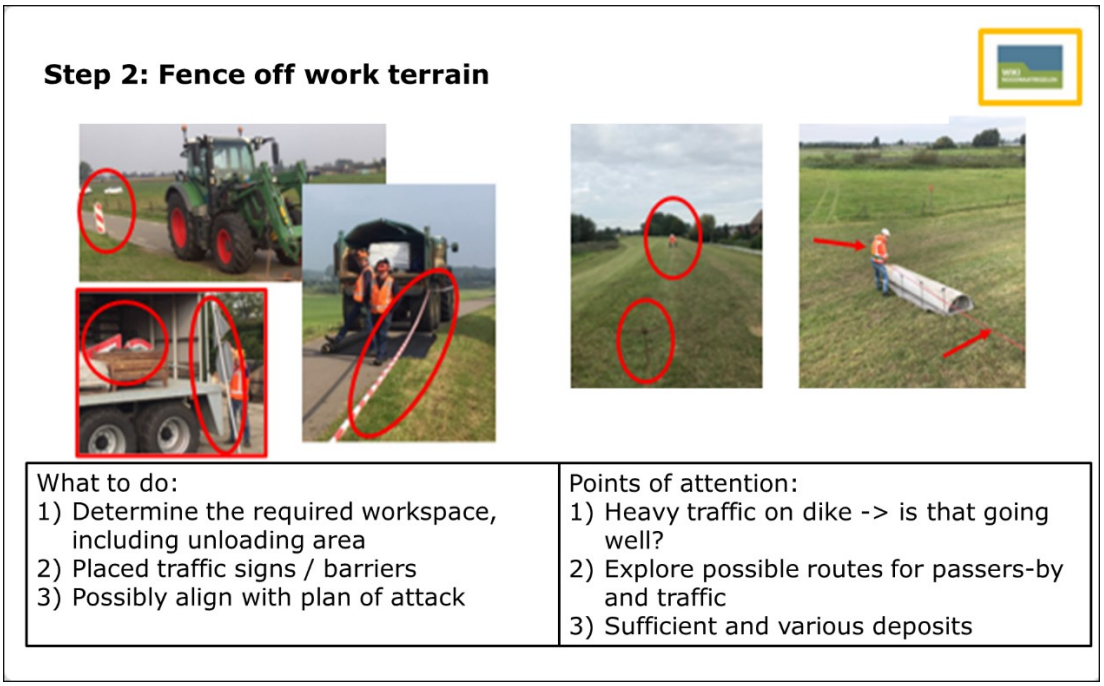
Step 1 – Plan of attack



Points of attention and considerations:

- This is the first step. It may seem that you are repeating yourself here, but the previous two slides served more to provide an overview and insight. It gives users something to hold on to.
- This first step is serious, go through the points one by one!
- Name the risks: see this as a Last Minute Risk Assessment!
- With regard to cables and pipes, in addition to what you have received, also look around you to see if there are any markings (e.g. posts) from utility companies.

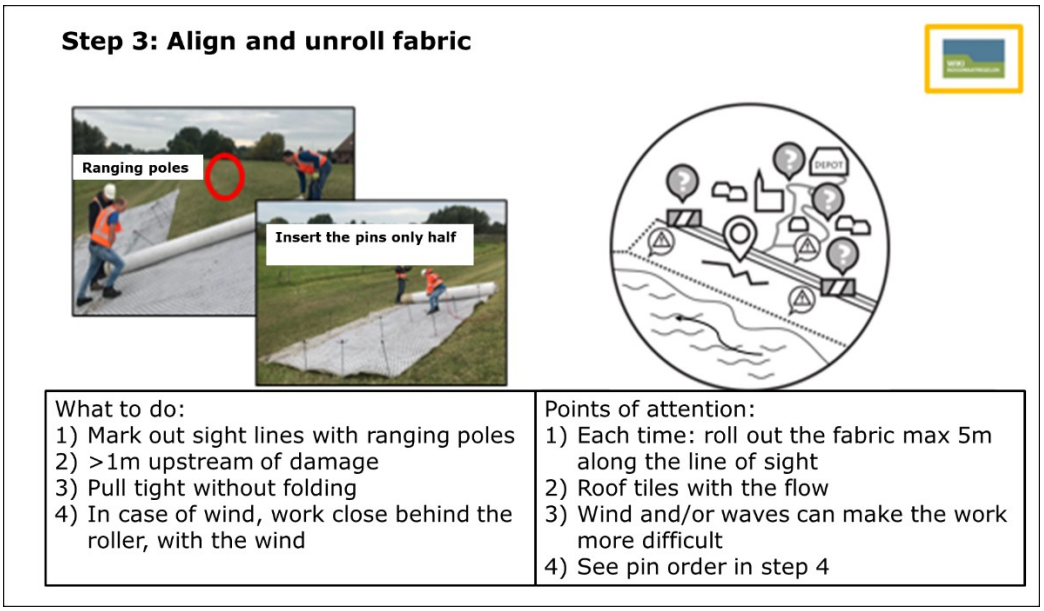
Step 2 – Fence off work area



Points of attention and considerations:

- On the one hand this concerns the fencing of the area, but on the other hand it is about marking out where the covering should be placed.

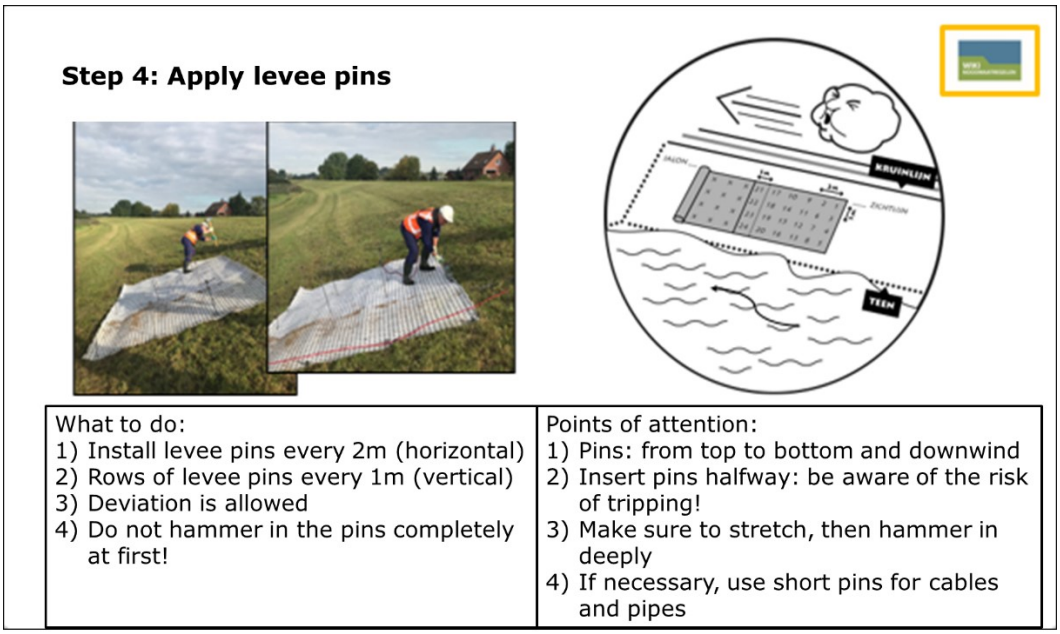
Step 3 – Align and unroll fabric



Points of attention and considerations:

- If you apply more than one piece of clamping, you must take into account overlap. We call this roof-tile structure. The way in which this is achieved depends on the load. This can be wind, current or waves. The point here is that this tax cannot go "below".
- Properly stake out using ranging poles/rods.
- Also, when unrolling the fabric, take the load into account! Make sure you roll off with the load (e.g. in the wind, with the wind).
- When rolling out, make sure that the geotextile is at the bottom and the grid is at the top.
- Preferably do not walk on the fabric, this will cause creases / less tightness. However, deal with this practically and just pay attention to folds / less tight fabric.
- Apply 2 rows of pins on fabric overlaps. This is because the damage is often just below the overlap, in the middle of the bracing. You definitely want to prevent the center overlap from opening up.

Step 4 - Apply levee pins

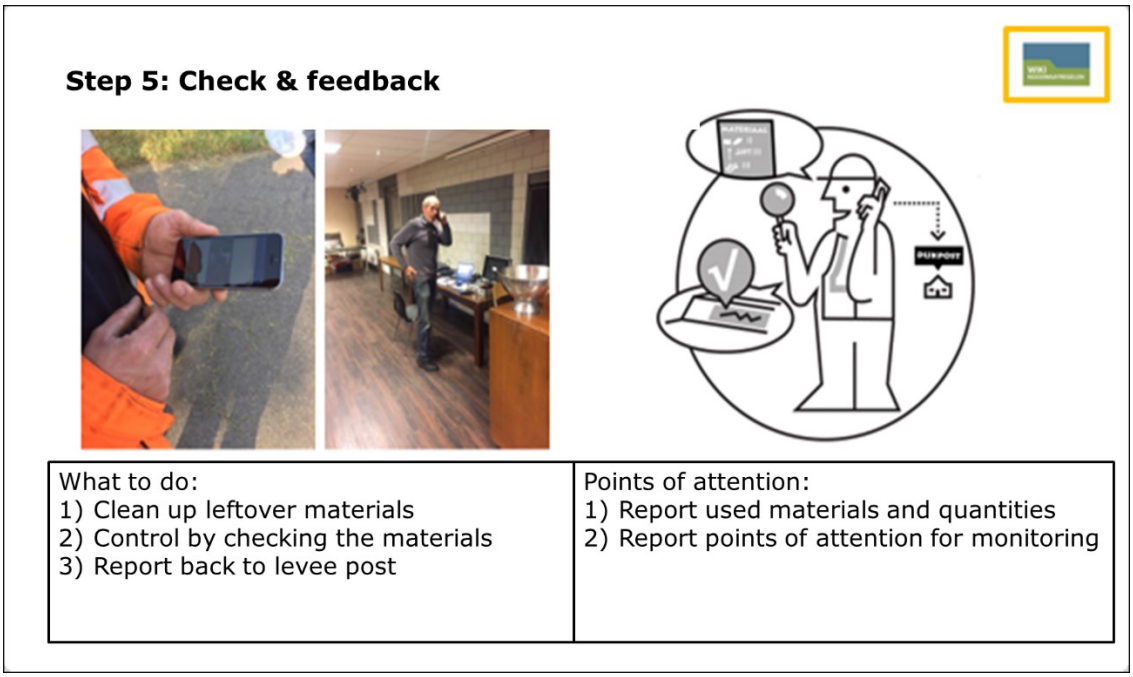


What to do:	Points of attention:
1) Install levee pins every 2m (horizontal) 2) Rows of levee pins every 1m (vertical) 3) Deviation is allowed 4) Do not hammer in the pins completely at first!	1) Pins: from top to bottom and downwind 2) Insert pins halfway: be aware of the risk of tripping! 3) Make sure to stretch, then hammer in deeply 4) If necessary, use short pins for cables and pipes

Points of attention and considerations:

- Decide on the fixation pattern at the start. The work instructions assume 2 X 1 m, but it is also deliberately stated that deviations are allowed. For example, sometimes a pattern of 1 X 1 m is better in connection with the prevention of (further) erosion or in windy conditions. However, please note: you have received a limited number of pins, so think carefully in advance.
- In principle, first drive in the pins in half. This gives you the option to adjust so that the covering is tightened.
- When (half) driving in in the pins, check whether the pins are tight enough. If the surface is loose, you will need more pins. Report this in time.
- In the work instructions, a sequence is recommended by means of numbering. It is possible that due to the presence of (strong) wind, a different order of driving in pins is useful. Be flexible here, deviations are allowed, the point is that it is placed close-fitting.
- Inserting the pins halfway and later fully inserting them can cause you to trip over the pins, with the risk of injury.
- Cutting the geotextile with geogrid is a dangerous moment. Ensure focus and work safely. Pay attention to the surface, as a grass covering no problem, but when it is paved it is wise to place something under the fabric when cutting (e.g. a board if available).

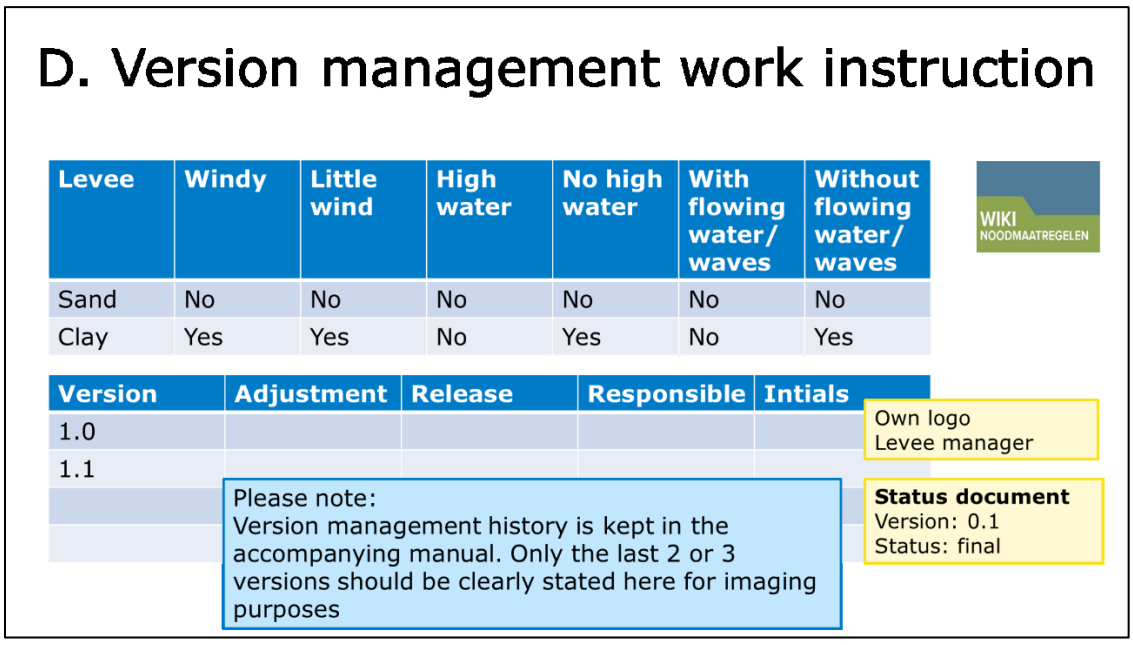
Step 5 – Check & feedback



Points of attention and considerations:

- This is the final step and is passed on so that it is clear that this damage has been repaired and that you do not have to worry about this in principle.
- There may be points of attention that need to be reported. This may include changing circumstances, for example that one has to check again whether the restraint is still sufficient. Think of rising water, more wind, etc. Make sure it is clear what monitoring is required and pass this on.
- Reporting back used (and therefore leftover) materials is important because they may be used elsewhere.

Version management work instruction



Points of attention and considerations:

- Make sure you are aware of the latest version.
- Version management concerns steps taken within the Wiki Emergency Measures working group. It is possible that the flood defense manager himself wants to take additional steps before the work instruction is put into use. The administrator is of course free to do so. This can of course be processed in the PowerPoint version of the work instructions.
- However, there is a friendly request to pass on changes to Wiki Emergency Measures because these are of course also opportunities for further improvement of the work instruction. See also section 4.12 for passing on evaluations.

During the wiki meeting on November 29, 2021, it was agreed that the history of the version management will be included in this guide.

See below:

Version	Amendment
0.1	Original work instructions for mountings (Water Authority Groot Salland)
0.2	Working version for Wiki Emergency Measures workshop on December 2018, partly based on research by Guido van Rinsum.
0.3	Working version for Wiki Emergency Measures workshop on May 1, 2019
0.4	Working version following workshop Wiki Emergency Measures on August 21, 2019
0.5	after trial at WDOD on Sept 10, 2019
0.6	Working version with cartoons "in one style" on Apr 17, 2020
0.7	Working version with correct reference CROW 96B on August 20, 2020
0.8	Processing trials WDOD, Rozema, IJmuijden, LLHPP on February 18, 2021
1.0	Process comments, in line with Guidance, agreed by the Wiki Emergency Measures working group on June 16, 2021
1.1	Processing of comments by Wiki working group on 29 Nov 2021 (title, dry only, cartoon slide 8 larger) on 29 November 2021

Evaluations

Both this guideline and the work instructions are not static documents. Applying coverings will regularly lead to new insights or learning points. It has been agreed within the working group that it is useful to approach the evaluations systematically and to create an evaluation form for this. A first version of this form was discussed on November 29, 2021. The suggestions are incorporated in the following. This form can be downloaded separately. See Appendix B.

5. Experiences

Overview of exercises held

Examples of exercises where this type of covering was used are shown below:

- WDOD and at WSRIJ, 2018, exercise Deining & Doorbraak
- WDOD, September 2019, Exercise near Zwolle
- Water Authority Hunze & Aa's, October 2020, Exercise near Rozema
- IJmuijden, November 2021

Reports of this exercise can be provided if required. See chapter 6 for contact persons and accessibility.

Furthermore, extensive research was conducted in 2021 on various geotextiles and coverings in the Hedwige-Prosperpolder. The findings of this are presented in Appendix B.

Experiences - What happens after application and when does deployment make sense?

It is important to know what to expect after application of a covering. What processes and forces then act on the stapling? Coverings can be placed on both the outer and inner slope as erosion protection. Depending on the position of the covering on the levee, different forces act on the covering:
- Outer protecting cover layer: loads due to wave run-up, wave overtopping and backflow of water; in addition, loads due to drift debris and logs.
- Inner protecting cover layer: (wave) overflow, wave overtopping, outflowing water from levee core.

The loads on a covering on the outer slope are much higher than on the inner slope. This means that the geotextile and staples must offer much more resistance when placed on the outer slope than when placed on the inner slope, where the water all flows over it.

Loose floating wood (flotsam) around in the form of tree trunks, for example, is a much higher danger of damaging the geotextile covering than the loosening of the covering as a result of wind and wave loads, and therefore continuous monitoring during high water situations is recommended.

However, UV radiation from the sun also affects the strength of the fabric the longer it is exposed to the sunlight. To achieve good UV resistance of the covering material, substances must be added to both PE and PP. For longer and repeated application of the stapling, it is recommended to purchase geotextiles with good UV resistance.
Another question that also arises is whether a newly reinforced protecting layer where the sod has not yet developed will provide sufficient resistance to erosion.

With limited wave attack as in the river area, it is not necessary for safety reasons to cover the protecting layer on the outside slope after seeding because a properly designed clay top layer is relatively thick. The clay layer is sufficiently erosion-resistant that it does not pose a safety risk during high water. You can then fall back on the residual strength of the remaining clay layer. Also, in the light of the actual flood probability approach, damage to the turf during a limited wave attack as in the river area is not a problem. Therefore, it can be assumed that it is not necessary to protect the protecting layer with additional measures during the accretion phase. On an oily clay layer a turf will not develop as well. However, a substrate layer that is only needed to allow the turf to grow faster and better can be eroded during a high water situation. Damage to a recently sown turf can also be repaired after the flood period and then re-seeded.

Only if the new clay layer is so badly damaged by floating tree trunks, for example, that the remaining layer thickness no longer seems to have sufficient erosion resistance, must it be protected from further erosion with covering.

One problem is that at high tide it is almost impossible to walk on a freshly applied clay protecting layer to remove drift debris and tree trunks. Drift debris would therefore be better removed from the water's edge when the clay layer is freshly laid. The same applies to tree trunks because removal from the protecting layer is only possible with heavier equipment. A covering would also not provide sufficient protection in this case.

Knowledge gaps
Various water authorities have indicated that they would like to know what minimum requirements must be set for a geotextile for a taping (for example in terms of tensile strength, permeability, light transmission), so that sufficient suitable material can be stocked in time (for example via a kindle agreement).

Geotextiles have not yet been tested in practice under normative loads for an application such as covering. It is therefore not known which forces actually act on a covering under the different load conditions (wave run-up, wave impact, wave overtopping, wave overflow and load due to floating debris).

Deltares has developed a simple theoretical model for protecting layers on the outer slope to determine the forces and deformations on a geotextile that is used to protect a not yet fully developed turf against wave attack. The model is based on calculation models that have been developed in research into set stone and pile protecting layers. Water then runs along the protecting layer from top to bottom, and the incoming wave then pushes the water from bottom to top. At the boundary between the two water flows, differential pressure can arise over the geotextile, pushing it off the slope.

It is therefore still a theoretical model to which only a kind of 'finger exercise' has been applied so far. It is therefore not a proven design method, but gives an idea of the order of magnitude of forces and bulging.

The model shows that for the geotextiles examined during the expected wave 'attack', the load on the geotextile is small enough for a stable construction with a bracing whereby a pin is driven through the geotextile every square meter.

From this follow the minimum requirements for a geotextile :
- Water permeability perpendicular to the plane (EN ISO 11058 Δh = 50 mm): > 25 mm/s
- Tensile strength at 5 % elongation (EN ISO 10319): > 40 kN /m
- O_{90} (EN ISO 12956): > 140 µm, but also < 300 µm
- Dynamic puncture resistance ((cone drop) EN ISO 13433): > 10 mm

Based on this, test sections can be constructed, but further research is certainly needed to validate the model. However, real wave loads are necessary for this. This is necessary to test whether the pins are heavy enough and whether the geotextile is not (partially) pulled off the slope.

However, the wave overtopping generator can be used to test the influence of a bracing with a geotextile on erosion. The geotextile will absorb part of the shear stress that would otherwise have to be absorbed by the slope (grass and clay).

How much protection geotextiles offer against erosion from running water could be tested with this and also what the differences are between different geotextiles.

6. Closing word

This guide was created in 2021, partly as a result of a session held on 8 February 2021. Various employees of the members of the Wiki Emergency Measures working group have joined forces. However, even before that time there were many meetings and exercises that contributed to the content of this guide as well as to the content of the work instructions.

Contributions have been made by various members of the Working Group Wiki Emergency Measures. Without wanting to shortchange anyone, we would like to take this opportunity to thank a number of members in particular for their input:

- Wijnand Evers, Water Authority Drents Overijsselse Delta
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- Arjan Krikke, Water Authority Rivierenland

Final editing:
- Ulrich Förster, Deltares / Wiki Emergency Measures
- Eric Huijskes/ Wiki Emergency Measures

In addition, the following sources have also been consulted and may be interesting as a reference:

- CIRIA, 2013, The International Levee Handbook
- Water Authority Rivierenland , work instruction “Procedure Leggen Dijkzeil”
- Water Authority Groot Salland (thans WDOD), work instruction “Aanbrengen van een bekramming" 1