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Field research on animal burrows and discontinuities in embankments


Foto: Vilda-Yves Adams

Adaptation to climate change

Field research on burrows and discontinuities in embankments

Fact Finding field research in the Hedwige-Prosperpolder

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1 Introduction

The Polder2C's project aims to gain an improved insight into the effects of climate change on the required flood protection of the hinterland. The knowledge, information and data that are collected is a valuable basis for future choices and applications in the field of safety against flooding.

The first overflow and overtopping tests of Polder2C's, executed in the winter season of 2019/2020 were aimed at acquiring new insight in the occurrence and effects of these failure mechanisms and their influence on dike strength. During these tests, mechanisms were identified that exhibited symptoms related to piping. Sand transporting water flows were observed on the inner slope of the dike, emerging from holes in the cover layer and in some cases resulting in erosion of the sand core of the levee.

On the location of Patrik's-cliff on the Scheldt-levee (Belgian part of the Hedwige-Propserpolder) during one of the field experiment a large subsidence took place. The damage that occurred erode the clay cover layer and eroded part of the sand core. This damage was repaired with rock bags as part of a Polder2C's emergency exercise. The rock bags were a to be validated repair measure for these kinds of damages.

During subsequent Polder2C's exercises in the field waterflow was planned to hit the rock bags to test their erosion-resistance. During these exercises, performed on the 30th and 31st of March 2021 waterflow was initially diverted past the rock bags. However, even whilst the water was being diverted, water flow could be heard and seen taking place underneath the rock bags. The water flow started to erode sand and subsidence of the rock bags took place. Water flows were also detected visually through the clay cover layer on the location of Patrik's cliff.

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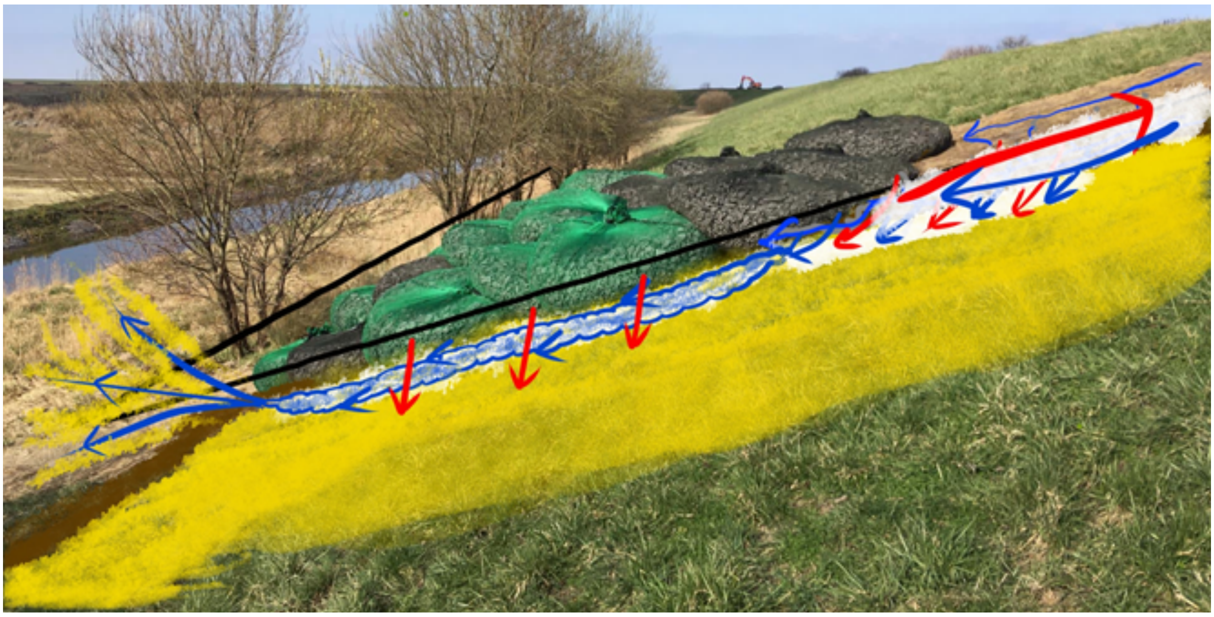

Figure 1 Sketch of assumed mechanism. Blue arrows sympoblise the water flowing from the top of the levee through preferential flow paths, underneath the rock bags where sand is picked up. The red arrows indicate what happens: subsidence of the rock bags and erosion of the sand core and damage of the clay cover above the rock bags.

Questions about the origin and flow paths came to mind: what was observed on site? How did the water flow through the cover layer? Could this water be the cause of sand eroding from the inside of the levee? It was then decided by STOWA and Rijkswaterstaat that further fact finding research to clarify the observations made needed to take place on short notice. This project was overseen by a project team whose members are mention in Appendix II: Organization.

1.1 Problem definition

In the Dutch and Flemish approaches to the safety of grass-covered embankments against overtopping (either by steady overflow or by wave overtopping), the focus lies on degradation and erosion of the grass cover including the sod layer. After erosion of the top clay layer of the levee, erosion of the sandy core can take place, possibly resulting in a breach of the levee if erosion progresses enough.

Erosion according to the piping mechanism (sand transporting water flows), in which erosion occurs underneath the clay cover, has not been considered so far. The situation as was encountered is comparable with concentrated leaks and contact erosion as mentioned in (International Commission on large dams, 2017) and described for a series of tests carried out in 1993 at the dike near Wissekerke by Galiana (2006).

The encountered holes in the top layer of the levee and their influence on the (rapid) deterioration of the cover layer when subject to significant overflow conditions, raise questions to the occurrence of such holes, their origins and their influence on erosion process, therefor on the safety against overflow.

A concern is that the assumptions on the continuity of the clay cover (i.e., absence of fissures and holes through this cover) are violated. According to Annex D.2 of the Dutch guideline on grass covers, part of the

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safety assessment of dikes (Ministerie van Infrastructuur en Waterstaat, 2021), no fissures and holes should extend all the way from the surface through the sod and clay layer to the sand core to allow for the application of the default formulas, which include a combined partial safety factor for uplift of the cover layer of 1.21. Otherwise, this factor is increased to 2 while also the outflow of sand should be checked for. For the latter, the mentioned guideline gives some formulae too. It is noted however that these formulae assume that the exit hole near the toe of the dike is (roughly) vertical. For more horizontal holes it is explicitly stated that the given formulae are not valid and it is recommended to investigate the probability of occurrence of such holes, and the consequences on the safety of the dike. Such holes are however currently not part of this guideline.

1.2 Research goal

The aim of this research is to execute a (short-term) fact finding field research in which the locations and the extent of preferential flow paths, burrows and/or discontinuities including their entry and exit points are investigated. The gained insight of this research can be used as foundation of a broader research involving more levee-sites with comparable issues, incorporation of relevant literature and more thorough analysis.

1.3 Research questions

The main research questions to achieve the research goal are:

1. Regarding the entry point (or zone of entry) of the water in the cover layer
    a. Does the road on the crest of the levee influence the entry of water? [1]
    b. To what extent do burrows and other discontinuities determine the entry point of water?
2. Regarding the exit points of the water flow
    a. Can exit points be identified by infiltrating water in entry points?
    b. To what extent do the rock bags influence the exit point of the water flow?
3. Preferential flow paths of water
    a. What are properties of the existing preferential flow paths? Are the flow paths caused by animal activity?
        i. How are the preferential flow paths, burrows and holes situated in the levee?
        ii. To what extent has a network of burrows and holes formed?
    b. To what extent is waterflow related to the presence of the rock bags?[2]

1.4 Research approach

To answer the research questions the following steps are followed as mentioned in Figure 2.

[1] To enable a comparison, a second site is examined, where no road is present on the crest
[2] For reasons of comparison and generalisation, the second site location has no Rock Bags down the slope and has a larger thickness of the clay cover.

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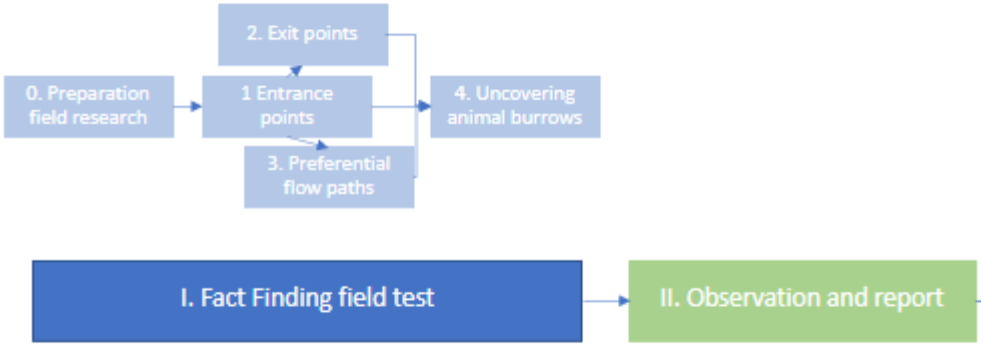

Figure 2 Overview of the research steps

Below these steps are described in more detail; both how they were conceived and how they have been executed in the field.
Scope of short-term research.
An initial field visit was planned over a time span of 2 days in order to get a better understanding of the actual situation on site. The following steps were carried out:

0. Preparations
1. locating entry points
2. locating exit points
3. indicate the whereabouts of potential preferential flow paths

The locations of interest that were found during the initial field visit at the Dutch and Belgian sites are presented in figure 3.

Figure 3 Test locations at the Belgium and Dutch site of the Hedwige-Prosperpolder

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A second field visit of 3 days was executed aimed at uncovering preferential flow paths, burrows and discontinuities and their extent in the cover layer and potentially the sand core of the levee. For the uncovering of the preferential flowpaths, burrows, etc. fast-setting concrete (quickly hardening concrete) was used.

Based on the results of the fact-finding field research a quick-scan of relevant further research was carried out based on expert-judgement of the project team. This was worked out in more detail in a separate memorandum.

1.4.1 Guide for this report

This report describes the results that were found during the fact-finding field research. It is therefore not a deeply analysing report but tries to portrait the findings of the fact-finding field research as objective as possible.

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2 Results first part field experiment

This chapter describes the results and observations during the first field fact finding activities. These activities were aimed at:

- preparing the location for the field research;
- finding entry and exit points of preferential flow paths;
- and selecting locations in The Netherlands and Belgium (**Fout! Verwijzingsbron niet gevonden.**, chapter 1) where during the second field visit the size and location of the animal burrows would be determined by filling them with fast-hardening-concrete and consequently excavated.

2.1 Results site The Netherlands

2.1.1 Preparation field research

The grass on the Dutch side of the border had been mown recently. Therefor visual inspections were quite good to be executed.

At the Dutch site presumed animal burrows and other discontinuities were observed. A large rip with a length of 25 to 30 metres with a depth of at least one metre (a 1 metre probe could effortlessly be entered over its full height at various locations along the rip), possibly caused by a locally slid clay cover, was observed. The observed local sliding of the clay cover resulted in rip in the clay cover. At the toe of the levee near the rip moist-loving vegetation (reed) grew (see Figure 4). The rip could, as was presumed, have made a connection with the underlaying sand core (not touched with the aforementioned probe).

It was decided that upwards to the crest of the dike, from the location of the reed at the toe of the dike, the research team would search for entry and exit points.

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Figure 4 Rip observed at Dutch location 2 meters above a small reed vegetation, shown in both pictures.

2.1.2 Entry and exit points

Visual inspections were carried out to find possible entry points. When holes were found, a quick assessment was made to determine whether these holes were of animal or human origin. Mainly on the Belgian sites a lot of traces of the previously executed experiments were still present, as such holes in the top layer where ankers, poles, etc. were installed.
Presumed holes of animal origin and cracks possibly caused by draught or sliding/subsidence were marked yellow (see Figure 5). Holes of human origin were marked orange.

Figure 5 Holes of animal origin or cracks are marked yellow

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After identifying and locating potential entry and exit points, water was infiltrated in the presumed entry point using a flow rate of approximately 0.3 l/s. Where water was observed to flow out, this was marked an exit point. However, during the water flow test, water was also observed to flow out of the cover layer at various other points. This prohibited the water flow to be constant through the flow path in the cover layer. So the current of the water flow was increased by placing the water hose directly in the holes with a water flow current of approximately 1 l/s. This resulted in better visible exit points.
For site location 2 in The Netherlands, several exit points were clearly observed (Figure 6).

Figure 6 Identification of exit point

The identified entry and exit points were marked for application of fast-setting concrete in the second field visit.

2.1.3 Preferential Flow Paths

Based on visual observations, location of entry points were subjected to flow rates of ca. 1 l/s (see Figure 7). These flow rates made it possible to observe preferential flow paths, because of the visible water flows at the exit points. Above the reed zone at the toe of the levee, the water did not appear at the surface but seemed to disappear in the core of the levee. With use of a hand-held-inspection-probe (Dutch: *prikstok*, e.g. visible in the upper picture in Figure 4) the observed rip which may have caused the water to flow internally away was inspected.

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Figure 7 Identification of preferential flow paths due to water infiltration

2.2 Results site Belgium

2.2.1 Preparation field research

During the initial field visit little to no changes were observed in comparison with previous visits. Based on visual inspection, and the previous use of paint-markers, the rock bags appeared to be at the same place and orientation as they were left behind at the end of March 2021. The grass cover had grown very high at this location since mowing activities have not taken place here recently. Therefore, the grass was mown (Figure 8).

Figure 8 Preparation of test location, mowing grass

At site location 1, based on visual inspection it was concluded that the presence of burrows and discontinuities seemed to be in the same order as during the visit of March 2021. During

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the field tests the V-shaped sandbags at site location 1 was kept on the same place as where it was placed in March

2.2.2 Entry points

To find the entry points visual observations were executed. Both man-made-holes were found and (presumed) holes of animal origin. Man-made-holes were marked orange, holes of animal or otherwise natural origin were marked yellow (Figure 9). After identifying and locating potential entry and exit points, water flow tests were conducted. Based on these test the exit points were found and marked for application of fast-setting concrete during the second field visit. Biological degradable colourant was used to identify and validate presumed flow paths in the clay cover of the levee. This way the connection between entry and exit points was proven.

Figure 9 Marking burrows and discontinuities that are suspected from human interventions(Yellow) or from animal activities (Orange)

The presence of the Rock Bags on the Belgian site (Patrik's cliff) prohibited the determination of the exact location of the exit points (Figure 10).

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Figure 10 Untraceable exit points nearby the rock bags

As test infrared measurements were carried out during the test to identify the exit points of the water flows (Figure 11). Although these infrared measurements detected a difference in temperature on the locations where water flowed out of the exit points, the infrared measurements were of no added value during the field test because the exit points were clearly visible.

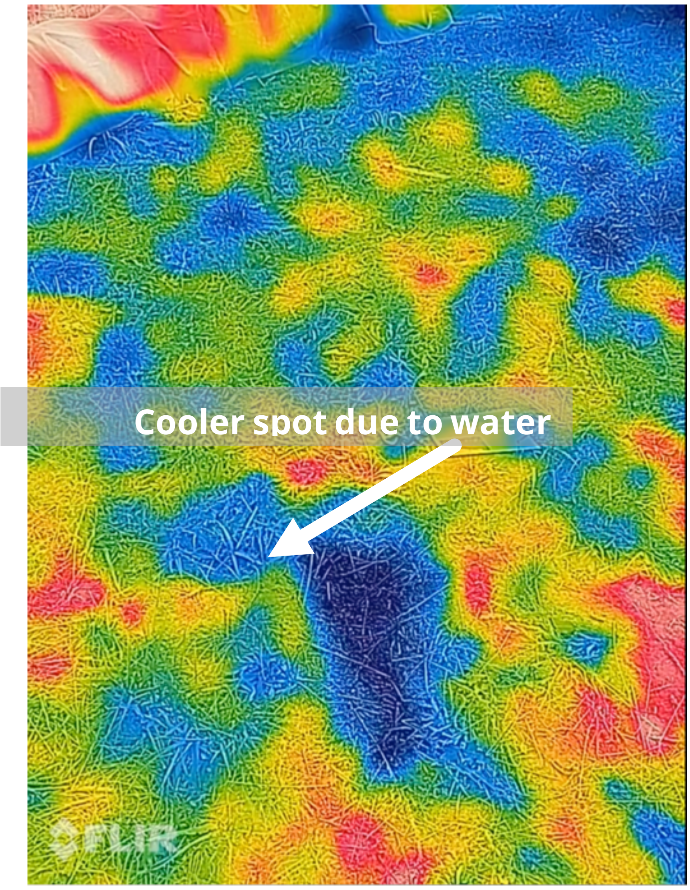

Figure 11 infrared measurements

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2.2.3 Preferential Flow Paths

After appointing presumed locations of entry and exit points water flow test were carried out to determine if preferential flow paths existed in the clay cover. Water, at a flow rate of approximately 1 l/s, was poured into the presumed entry point. After a few minutes a potential preferential flow path was identified. To confirm the presumptions of the field team a biological degradable colourant was successfully used (Figure 12).

Figure 12 Application of colourant to find preferential flow paths

2.3 Locations of interest for second field test

During the first fact finding field tests three location were deemed to be of interest for application of fast-setting concrete and two locations were deemed to be of interest for digging a trench to gain insight in the stratification and soil composition of the cover layer on that specific location. The latter was done because during field inspection a remarkably soft spot in the cover layer was found when using a hand-held-inspection-probe (Dutch: *prikstok*).

Experience acquired in previous applications of fast-setting concrete at mice burrows learned that moistening of the to be fixated burrow and preferential flow paths during the fast-setting concrete application and excavation is essential. As application and excavation of the concrete fixed burrows is time consuming, a limited size of the location where it is applied is essential.

2.4 Summary of important observations and results, first field test

The main observations and results of the first field test are formulated for both the Dutch and Belgian location.

2.4.1 Site The Netherlands

For the Dutch location the main observations are:

- Direct connections between different entry points and exit points were observed.
- Furthermore a direct link between preferential flowpaths, burrow, corridors or other since discontinuities and the sand core of the levee could not be observed yet, although at the lower

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part of site 2, at the southern section, water was infiltrated at a rate of at first 0.3 l/s and then 1 l/s for about 45 minutes without any sign of leakage. Similarly, at the scar water was infiltrated for an even longer period without any sign of saturation at the scar itself, nor of any leakage below. This suggests a connection to the sandy core or sand layer of the embankment. Application of fast-setting concrete during the second field visit might give insights in this information need.

Focus areas for further research:

1. Netherlands-southern row, at bottom
2. The Netherlands, north of the northern row, in a crack above the smaller reed zone (not the larger reed zone)
3. During the second field test a third location at the Dutch site is added as focus area because of potential mice activities nearby location. A trial trench was excavated proving the necessity for further research.

2.4.2 Site Belgium

For the Belgium location the main observations are:

- The entry point was situated near the side of the road. In the hole that formed the entry point course material (gravel, shells and potentially rubble) was found.
- Sounds were heard caused by flowing water underneath the rock bags.
- A direct link between preferential flow paths, burrows, corridors or other since discontinuities and the sand core of the levee was not observed during the first field visit.

Focus areas for further research:

1. Belgium, northern section, just above Rock Bags near Patrik's cliff.

2.4.3 Overview focus areas

The Dutch and Belgian locations for the field test are displayed in the overview map below.

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Figure 13 Focus areas at the Dutch (red) and Belgian (Yellow) side of the Hedwige-Prosperpolder

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3 Results second part field experiments

During the second field test the main goal was to identify the extent of burrows and discontinuities at the pre-defined locations of interest. For these tests fast-setting concrete ("Egaline") was used.

3.1 Preparation and execution of field activities

Before starting the application of fast-setting concrete, the sites were prepared. This preparation consisted of mowing the grass and clearing the access to the entry and exit points. Small trenches beneath the exit areas were excavated to capture potentially overflowing concrete out of the exit points. Because of previously mentioned issues, only a limited length/area of the burrows was poured with concrete and consequently excavated.

During the concrete-application the upper level of the concrete mixture in the entry point was kept at a constant height whilst the exit points were blocked. From the moment the sinking of the concrete stopped, the burrows or discontinuities were assumed to be completely or sufficiently filled (Figure 14).

Figure 14 Entry point filled with fast-setting concrete

After a period of 24 hours the fast-setting concrete was sufficiently hardened and was consequently excavated with care. Measurements of the size and diameter of the excavated fixed holes, burrows and flow paths were taken. The executed measurements consisted of:

- Thickness of clay layers
- Depth of burrows and discontinuities
- Diameter of burrows and discontinuities
- Length of burrows and discontinuities

Pictures related to the measurements are given in

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Figure 15 and Figure 16.

Figure 15 a) Length measurements of focus area b) depth measurements of burrows. c) depth measurements of cracks

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Figure 16 Length depth measurements of mole burrow at Belgian site.

After finishing the excavation works at the site the concrete and other devices were removed. The concrete structure was removed and numbered for re-assembling purposes at later time.

3.2 Site The Netherlands

At the Dutch site location three focus-areas were identified (Figure 13). One that was relevant for comparison with the Belgian site location. And another, for a more detailed investigation to the observed cracks. Based on expert-judgement another location was identified as focus area because of potential mice-activities.

3.2.1 Properties location

At the more northern Dutch test location the levee is overgrown with some sort of reeds at the landside toe. Furthermore, a trail trench is made to determine the clay thickness at the levee slope, which was larger than 0.8 m. The inspection road is situated on a berm beyond the landside toe of the levee (cf. Figure 4 and Figure 13) . Other particularities at the site locations are:

- Focus areas of 4 by 3 meter (in case of mice location 2 by 2 meter)
- Levee slope ca. 1:3.5 (V:H)

3.2.2 Results Dutch site

The main observations and results of the first field test are:

- The mole burrows were situated at a depth of ca. 25 to 30 cm.
- The mole burrows have diameters of 3-5 cm
- The scars/cracks found during the first field visit have been partly disappeared during the second field visit. A probable explanation for this were the change in weather conditions. After a quite long period of relative drought, a longer period of rain fell between the first and second field visit due to which the soil could have swollen again.

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The measurements of the Dutch site are listed in Table 1. Pictures of the uncovered burrows are shown in Figure 17.

Location	**NL**		
Focus area	**1**	**2**	**3**
Type of activity	Mole	Crack	Crack and mice
Thickness of clay layers	>0.8m	>0.8m	>0.8m
Depth of burrows and discontinuities	0.25m	0.25m	>0.55m
Diameter of burrows and discontinuities	0.03-0.05m	NaN	NaN
Length of burrows and discontinuities	>4 m	>3.6m	NAN

Table 1 Measurement results. In which:
> : the value is measured but can be larger because the research area was confined.
NaN : values were not traceable in the field during this short term experiment.

Figure 17 Upper left: Hardened concrete was at 50 to 55 cm depth. Because of the combination of cracks and mice burrows the exact depth cannot simply be attributed to either one of them (Focus location The Netherlands 3). Lower left Interrupted concrete structure indicating the recovering of a crack (Focus location The Netherlands 2). Right: Mole burrow longer than 4m ((Focus location The Netherlands 1).

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3.3 Site Belgium

From the observations during the first field test it was concluded that there were direct connections between different entry and exit points. These connections seemed to have connection with the rock bags and interface with the underlying sand layer there.

3.3.1 Properties location

The Belgian site location distinguished itself by the presence of the rock bags at the inner slope and a ca 0.3 m thick clay cover. Furthermore, the inspection road is situated at the top of the levee. The entry point of water at this location seemed to be located near the foundation of the road on the crest of the levee. This was concluded after retrieving course material (gravel, shells) from the entry point aside of the road.

Other particularities at the site locations are:

- Presence of V-shaped sandbag-barrier
- Rock bags on the location of Patriks cliff (a damage occurred during overflow experiments)
- Levee slope of ca. 1:3.5
- Grass was mowed short before applying the fast-setting concrete

3.3.2 Results Belgian site

The main results from the second field test are:

- The mole burrows at the Belgian site location are connected to the sand layer.
- The found mole burrows are at a depth of ca. 25 to 30 cm.
- The maximum linear length of concrete fixed preferential flow path observed was about 3,40 m, which is only a part of the total length of the mole burrow.
- The mole burrows have diameters of 3-5 cm and diameters of 5-8 cm are found.
- The observed mole burrows are interrupted by the placed Rock Bags

Next to the mole burrows, cracks and mice burrows were observed.

The measurements of the Belgium site are listed in Table 2. Figure 18 shows the uncovered burrows and preferential flow paths of the Belgian site.

Location	**BE**
Focus area	**1**
Type of activity	Mole/human interventions
Thickness of clay layers	0.25-0.3m
Depth of burrows and discontinuities	0.30m
Diameter of burrows and discontinuities	0.03-0.08m
Length of burrows and discontinuities	>3.8m

Table 2 Measurement results. In which:
> : the value is measured but can be larger because the research area was confined.
NaN : values were not traceable in the field during this short term experiment.

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Figure 18 Mole burrow at Belgium location a) diameter of mole burrow, b) sandy materials, c) sand layer underneath the mole burrow

3.4 Observations both second field tests

The main observations of the second field tests are:

- The mole burrows at the Belgium site location were connected to the sand layer.
- The mole burrows found were situated at a depth of 25 to 30 cm.
- The maximum linear length observed was about 3,40m, which is a part of the total length of the mole burrow. Due to time constraints it was not possible to apply fast-setting concrete and excavate the whole of the preferential flow paths and/or animal burrows.
- The mole burrows corridors have diameters of 3-5 cm and at the Belgian site location diameters of 5-8 cm are found. It is suspected that the overflow experiments eroded and expanded present mole burrows and corridors.
- The rip found on the Dutch location in the first field visit seemed to have been partly disappeared. For during the second field visit they were not seen or were reduced in size. Interrupted concrete connection were found during the second field visit.
- Next to the mole burrows, cracks and mice burrows were observed. The depth at which hardened concrete was excavated was at a depth of 50 to 55 cm. Because of the combination of cracks and mice burrows the exact depth cannot simply be attributed to either of them [quote of Abel den Boer, made during the field survey].
- The observed mole burrows are interrupted by the rock bags. It is plausible to assume that the burrows were present before placing the rock bags, also because of the usual

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habit of moles in dike slopes to continue all the way down to the ditch to allow for covered access to water.

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4 Answering the research questions and follow-up

4.1 Answering research questions

An initial answer to the research questions is given based on a detailed description of the observations in the field.

1. *The entry point or zone of the water in the cover layer*
    a. *Does the road on the crest of the levee influence the entry of water?*

An unambiguous influence of the presence or absence of the road on the crest is not observed. However, the entry point at the Belgian location seemed to be located near the foundation of the road on the crest of the levee. In this entry point course material (gravel, shells and possibly rubble) were found. It is possible that this improved the permeability of the entry point and thus improved the infiltration of the water and its flowing through the preferential flow paths.

    b. *To what extent do burrows and other discontinuities determine the entry point of water?*

It was shown during the fact-finding field research that the entry points that were found and used in the water flow test were of animal origin.

2. *Exit points of the water flow*
    a. *Can exit points be identified by infiltrating water in entry points?*

Due to visual inspection and application of water flow tests exit points were located and identified. Furthermore, the use of colorant contributed in the traceability of direct connections. Multiple exit points were observed and not only one.

    b. *To what extent do the rock bags influence the exit point of the water flow?*

It can safely be concluded, also based on the finding on the Dutch location, that the damage of Patrik's cliff and the rock bags that were consequently placed on top of the damage cut through animal corridors. The precise exit point near the rock bags was not found because the rock bags could not be removed. Because the burrow was cut, the rock bags definitely were influencing the waterflow in downward direction directly over the sand core of the levee.

3. *Preferential flow paths of water*
    a. *What are properties of the existing preferential flow paths?*
    Are the flow paths caused by animal activity?
        i. *How are the preferential flow paths, burrows and holes situated in the levee?*
        ii. *To what extent has a network of burrows and holes formed?*

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Large connections of mole burrows along the dike slope with multiple exit and entry points were detected. The mice burrows were smaller in size, more concentrated and with relatively less entry and exit points.
In this particular situation the mice activities and accompanying cracks were situated deeper in the levee than the mole activities. The observed cracks at the Dutch site were situated relatively deep.
It was found between the first and second field visit that relatively large and deep cracks are able to partly recover themselves during wet conditions.

b. To what extent is waterflow related to the presence of the rock bags?

The damage of Patrik's cliff and consequent placement of rock bags as emergency repair measure, has led to interruption of the existing mole burrow connections and therefore interrupted the preferential flow paths through the mole corridor. However the corridors were cut, a new exit point was formed. Whilst executing the field emergency exercise on the 30th and 31st of March water flowing through the preferential flow paths recently located, it subsequently flowed out of the exit point directly on the sand core underneath the rock bags causing erosion to occur.

4.2 Follow-up

The results of this research were discussed with the project team. The following directions for further research are suggested by this project team:

1. Inventories the severity and commonality of animal burrows in levee by consulting/interviewing levee managers at waterboards, Rijkswaterstaat and international partners.
2. Determine the influence on Polder2C's experiments yet to be executed. Determine if in Polder2C's experiments further research to the impact of animal burrows in a worst-case scenario can be realised in one of the upcoming large scale field experiments.
3. Determine if by smart levee management and maintenance measures animal activity in levees can be prevented.

These options will be worked out in detail in a side note that will follow-up this report.

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Appendix I: Action plan

This appendix describes the action plan that is carried out during these experiments.

Table 3 Detailed description of activities during the field visit. X = done, A = Alternative elaboration

Steps	Activity	Method	Equipment and resources	Processed
0. Preparation field research	Preparation of assets	Check of the action plan	Action plan	X
	Visual inspection of test location	Visual inspection	Notepad and pen	X
	Determine 2 test locations	Visual inspection and expert judgement	Experts	X
	Estimation animal activity	Visual inspection and expert judgement	Notepad and pen	X
	Changes since previous visit (reference situation)	Visual inspection and experience from WP1	Notepad and pen	X
	Removal of V-shaped sandbag dam	Removal by hand	Several people	A
	Mow or remove grass cover	Mowing sods	Sod cutter	X
	Set zero-measurement of test location	Visual inspection, reporting and making pictures	Notepad and pen, photo camera	X
1. Entry points	Define location of entry points	Zero-measurement with IR and visual inspection	Notepad and pen, and IR	X
		Infiltrations test with colourant	Colourant, pump, power source, infiltration bags	X
		Visual inspection, and IR. Mark the entry points	Notepad and pen, and IR and marker	X
2. Exit points	Define location of exit points for location with and without Rock Bags	Zero-measurement and IR and visual inspection	Notepad and pen, and IR	X
		Applying low flow rate to saturate the cover layers	Colourant, pump, power source	X

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Steps	Activity	Method	Equipment and resources	Processed
		Applying higher flow rate for measurements	Colourant, pump, power source	X
		Drain and separate overflow current to avoid ongoing erosion and collection of currents and sand through burrows and corridors.	Drain, timer, scale. Measuring cup.	A
		Visual inspection and IR. Marker the exit points.	Notepad and pen, and IR and marker	A
3. Preferential flow paths	Expose the flow paths between the entry and exit points.	Visual inspection, application bright coloured water. Marker the exit points. Mark the interest area of the flow paths.	Colourant, pump, power source, and Marker.	X
	Determine flow rate between entry and exit points	Measure the flow rate at entry point and in drain.	Drain, timer, scale. Measuring cup.	X
		Determine if application of endoscope measurements is needed during field visit 2 based on first measurements	Endoscope and tension spring	X
4. Uncovering burrows and discontinuities		Preparation of site location. Excavation of small capture trench and closing exit points	Excavation tools	X
	Uncovering burrows and discontinuities at the entry points, exit points and between	Application of fast-setting concrete at marked investigation area in previous steps.	Fast-setting concrete mixture, water and mixing equipment.	A
		Excavation and detaching of the interest area	Excavation tools and tassel	X
		Record the site for comparison with zero-measurement.	Photo camera, diameter meter, tape measure	X

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Steps	Activity	Method	Equipment and resources	Processed
		Taking out the concrete connections and numbering for future assembling	Marker. Excavation tools	A
		Recovering location	Excavation tools and clay. Knifes	X

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Appendix II: Organization

The project organisation for this specific research topic exist of the following persons with corresponding roles:

- Marian Booltink (MB), STOWA and involved on behalf of STOWA in Polder2C's, WP2. Hoogheemraadschap de Stichtse Rijnlanden.
- Andre Koelewijn (ARK), Geotechnical specialist. Deltares. Establishment of technical based quality of outcomes and relate the type of tests to the research question as posed. Active involved from Deltares during the tests and drawing of the results.
- Davy Depreiter/Patrik Peeters (DdP, PP), Technical Projectmanager of the P2C's LLHPP project and mentor of the erosion tests. Active involved from MOW during the tests and drawing the results.
- Ludolph Wentholt (LW), STOWA. Establishing of a policy connection within the water safety sector.
- Mark Postma (MP), Rijkswaterstaat.
- Anco van den Heuvel (AvdH), Rijkswaterstaat. Flood Expert. Active involved from RWS during the infiltration tests
- Bart Vonk (BV), Rijkswaterstaat. Senior Advisor Rijkswaterstaat in water safety with focus on emergency and crisis management.
- Ron Hölscher (RH), BZ Ingenieurs & Managers. Member of the Project management Team of the P2C's LLHPP project. Project assistant in measuring and monitoring of levees. Active involved from BZIM during the test and drawing of the results.
- Wouter Zomer (WZ), BZ Ingenieurs & Managers. Member of the Project management Team of the P2C's LLHPP project. Expert in measuring and monitoring of levees, levee failure experiments. . Active involved from BZIM during the test and drawing of the results.
- Abel de Boer (AdB), Wetterskip Fryslân. Hands-on Expert animal related activities by levees and experienced in the application of fast-setting concrete.
- Niek Bosma (NB), Wetterskip Fyslan. Hands-on Expert animal related activities by levees

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Appendix III: Overview images

Folder name	Picture file name	Date	Location (Focus area)
LLHPP Foto's 17-18 juni 2021	DSC_0001 to DSC_0415	17-6-2021	Belgium 1
LLHPP Foto's 17-18 juni 2021	DSC_0415 to DSC_0425	18-6-2021	The Netherlands 1-2-3
LLHPP Foto's 17-18 juni 2021	DSC_0429 to DSC_0739	18-6-2021	The Netherlands 1
LLHPP Foto's 17-18 juni 2021	DSC_0734, DSC_0735 and DSC_0738	18-6-2021	The Netherlands 2-3
LLHPP Foto's 17-18 juni 2021	DSC_0739 to DSC_0761	18-6-2021	The Netherlands 2-3
LLHPP Foto's 29- 1 juli 2021	IMG_20210629_085602 to IMG_20210629_170339	29-6-2021	The Netherlands
LLHPP Foto's 29- 1 juli 2021	IMG_20210630_101328 to IMG_20210701_083858	30-6-2021	Belgium 1
LLHPP Foto's 29- 1 juli 2021	IMG_20210701_090137 to IMG_20210701_114616	1-7-2021	The Netherlands
LLHPP Foto's 30 juni 2021	DSC_0762 to DSC_0806	30-6-2021	Belgium 1
LLHPP Foto's 30 juni 2021	DSC_0806 to DSC_0885	30-6-2021	The Netherlands 2-3
LLHPP Foto's 30 juni 2021	DSC_0885 to DSC_0893	30-6-2021	The Netherlands 1
LLHPP Foto's 30 juni 2021	DSC_0885 to DSC_0893	30-6-2021	The Netherlands 1-2-3

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