Rijkswaterstaat
Ministry of Infrastructure and the Environment

Safety assessment grass revetments on dikes

Astrid Labrujere, Wim Kanning

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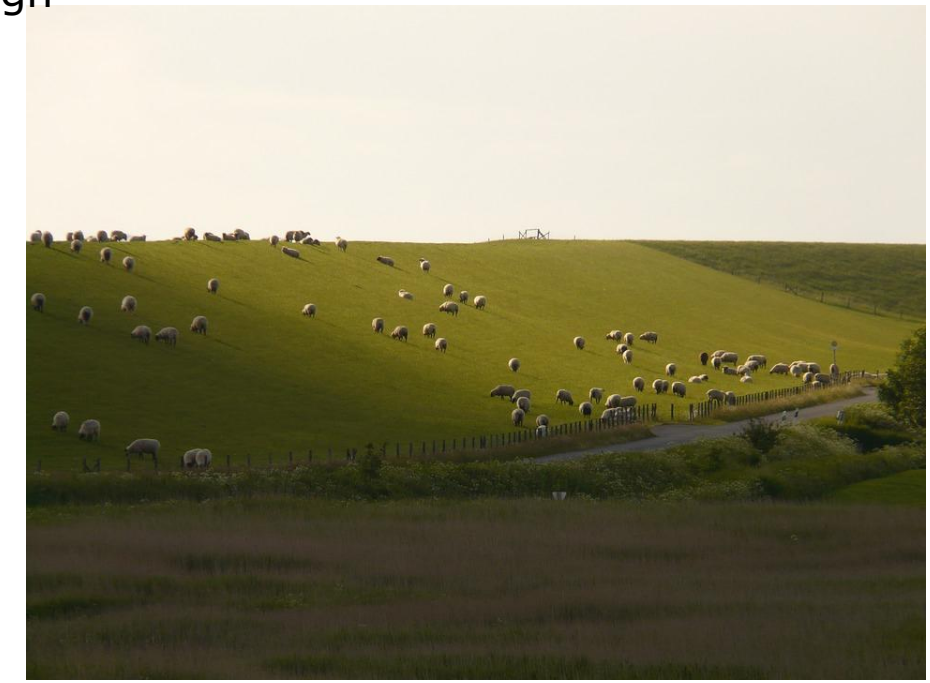
Introduction

- Astrid Labrujere – Rijkswaterstaat
- Executive Organisation of the Ministery of Infrastructure and Watermanagement
- Advise on policy for Watersafety (safety standards and assesment tools)
- Regional Water Authorities are responsibly for executing safety Assessments en reinforcement works

Rijkswaterstaat
Ministerie van Verkeer en Waterstaat

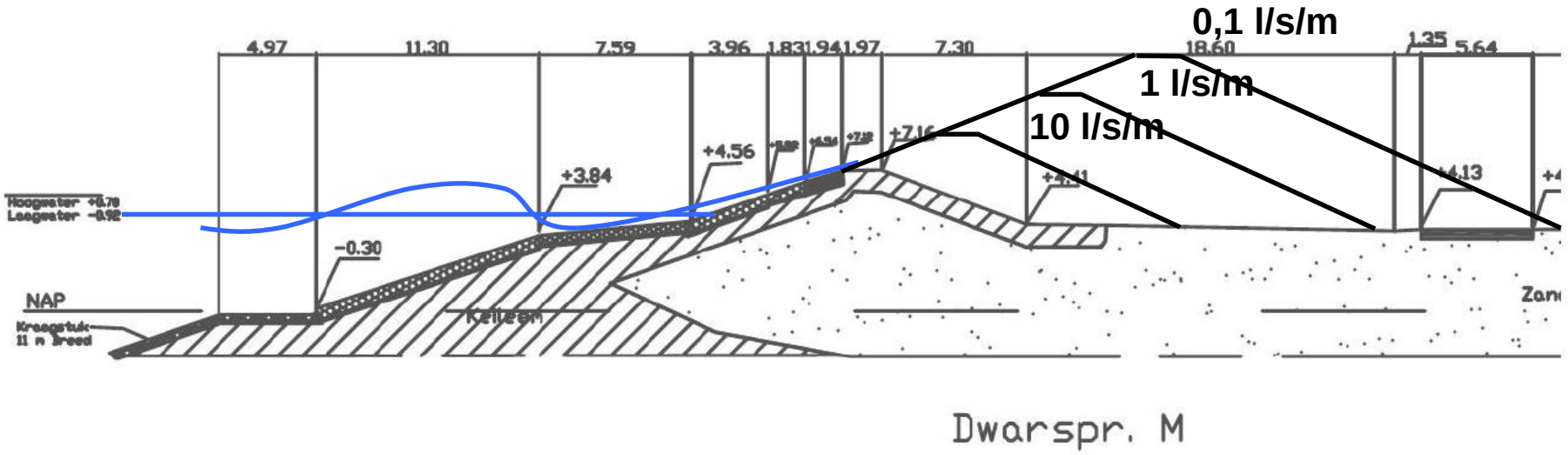
Content

1. Overtopping in General – What is the Dutch take on erosion
2. Overtopping in assessment and design
3. Knowledge gaps



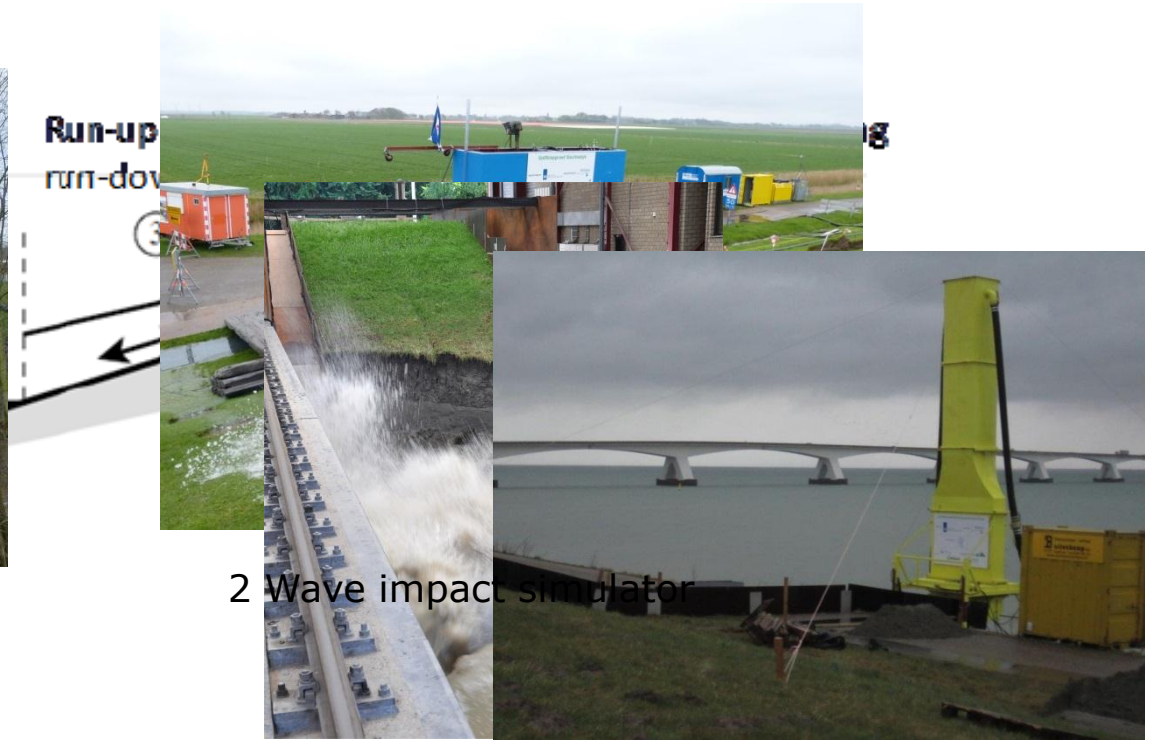
(1) General - Local estimate of impact

Crest free board	MSL +2,4 m	Overtopping 130 l/s/m
	MSL +4,5 m	Overtopping 10 l/s/m
	MSL +7,4 m	Overtopping 1 l/s/m
	MSL +9,2 m	Overtopping 0,1 l/s/m



(1) General – Testing (in situ)

5 Wave overtopping simulator



2 Wave impact simulator

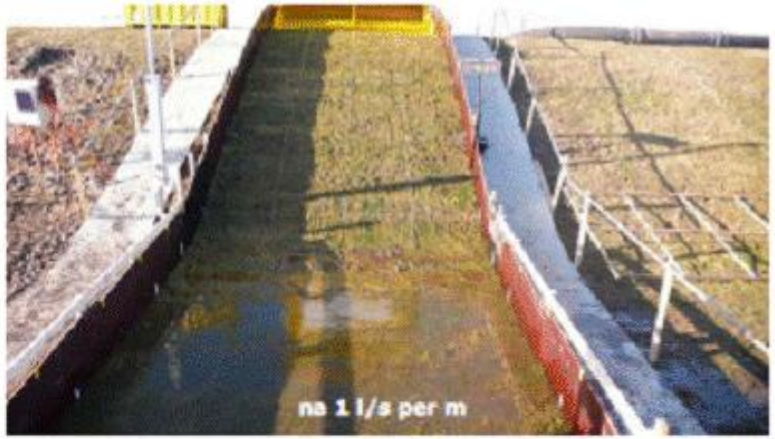
2 (+) Residual strength i wave flume

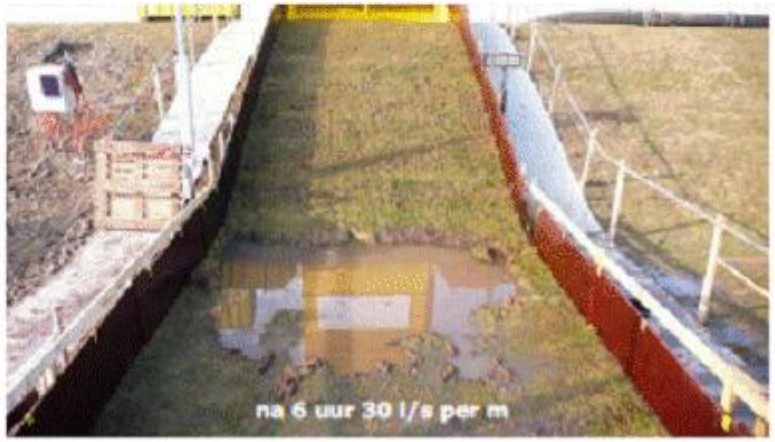
3 Wave run-up simulator

Movie

(1) Erosion observations

- Afsluitdijk strip 1 Damage development 0 – 1 – 10 – 30 l/s/m





(1) Erosion observations

- Afsluitdijk strip 1 damage development 50 – 75 l/s/m

(1) Erosion observations

(1) General - In short we learned:

- Closed grass sod is very strong
- Observed failure far beyond previous design criteria
- Closed grass sod in combination with very sandy soil still very erosion resistant
- Small objects or damages (like poles or mole holes) <0,15 m^2 do not weaken the grass sod much

However:

- Rough herbal growth to be avoided (very week compared to closed sod)
- Thin clay layer in combination with poor grass quality is very weak
- Transitions in geometry are significantly weaker (slope to berm)
- Transitions in revetment grass – hard are weak
- Transitions between grass and larger obstacles are weak

Closed sod

Gesloten zode

Based on visual inspection

- Mainly grass
- Representative open spots are smaller than 0,1m
- Open spots contain no more than 10% of the total surface
- Limited damaged spots

Based on inspection of a local sod

- Dense rootsystem
- Some effort needed to pull the sod apart

Open sod

Based on visual inspection

- Mainly grass
- Representative open spots are smaller than 0,1m
- Open spots contain no more than 25% of the total surface
- Limited damaged spots (more than closed)

Based on inspection of a local sod

- Easier to pull the sod apart
- And more difficult to take it out of the ground

Fragmentated sod

Based on visual inspection

- More than 25% of the surface as a plant distance of over 0,25m
- It concerns mainly individual plants which do not form a cohese root net

Based on inspection of a local sod

- Fragmentad root net wortelnet
- Almost impossilble to take out a grass sod

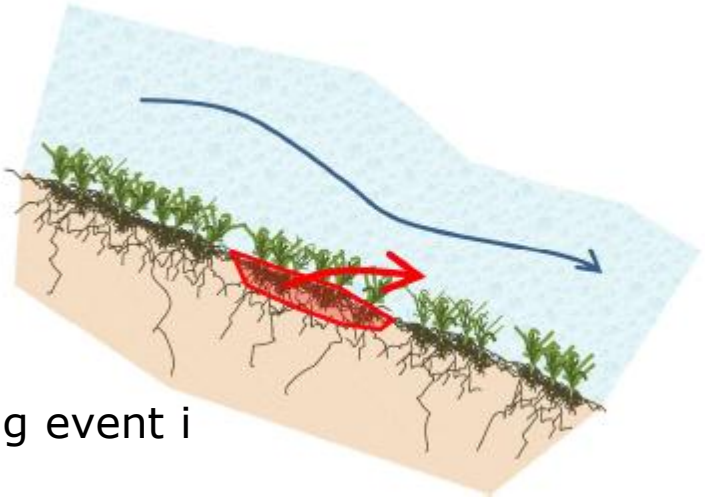
Assessment and design

- Elementry and detailed (two steps)
- The critical velocity depends on the quality of the grass (deterministic and based on field inspection by Local Water Authorities)
- On the inner slope we do not take residual strength into account yet (clay erosion)
- We do not take objects and transition into account, although we have done and are doing research in this area (a_S =1)
- But we believe overall it is a conservative concept

Detailed assesment

- Probabilistic model in our new Ringtoets assessment model: Resilience (based on erosion model) and Solicitation (hydraulic loads) are both stochastic variables

(2) Assessment erosion model



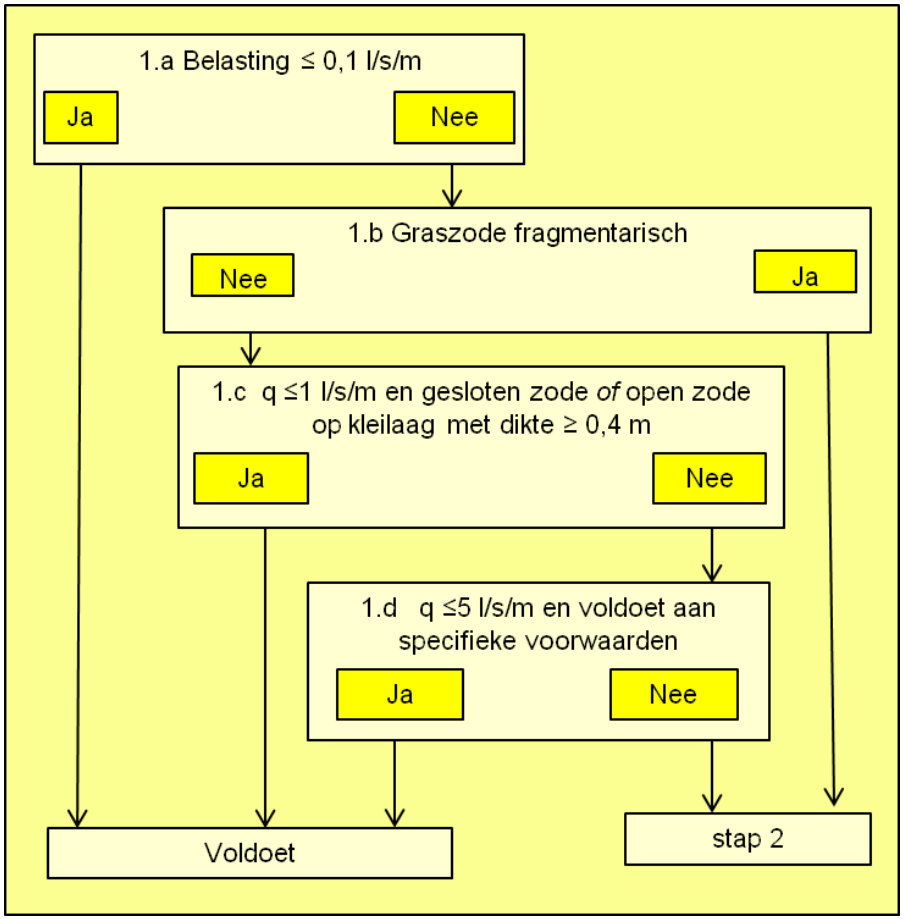
N: number of overtopping waves in storm
a_M: load increase at transitions
a_a: factor for acceleration depending on slope
a_S: strength reduction at transitions
U_i: maximum depth average velocity in overtopping event i
depends on overtopping volume and thus Hs
U_c: critical velocity

D: cumulative overload

≈ 1000 m^2/s^2 multiple spots start of erosion
≈ 4000 m^2/s^2 ongoing erosion (of the sod)
≈ 7000 m^2/s^2 failure grass revetment

$$D = \sum_{i=1}^{N} \max\left[\left(\alpha_M \left(\alpha_a U_i\right)^2 - \alpha_S U_c^2\right); 0\right]$$

(2) Elementry assessment

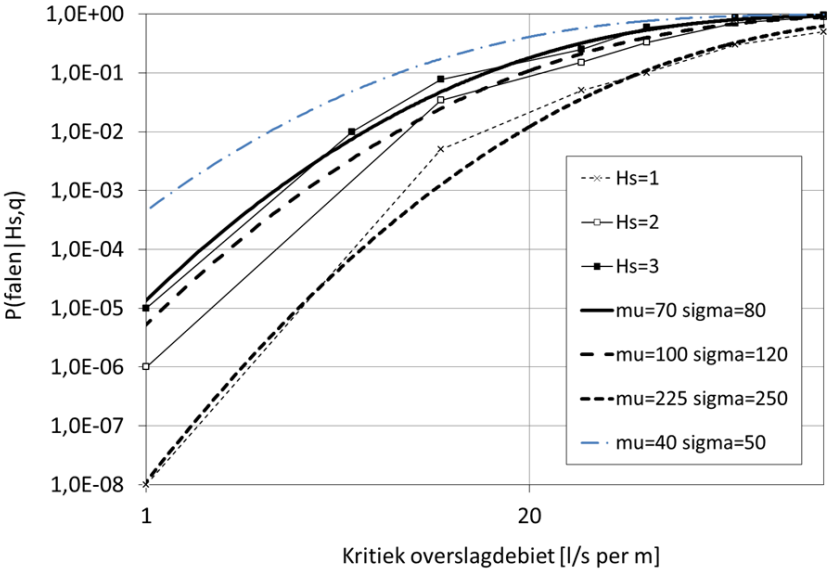


Specific Conditions

- Closed sod
- Overtopping discharge q is smaller than (or equal to) 5 l/m/s
- Wave height H_{m0} is smaller than 3m;
- Clay layer thicker than (or equal to) 0,4m
  or a slope less steep than 1:4;
- Size of objects is smaller than (or equal to) 0,15 m.

(2) Detailled assesment

- Probabilistic
- Critical overtopping discharge q, average and standard deviation as in graph
- Optionally adjust average and standard deviation
- Distributions based on wave height and dependent on erosion model



(3) Designing with higher overtopping discharges

- Local water authorities are carefull to upgrade to designing with higher overtopping discharges (5 and 10 l/m/s), because:
  - They might want a levee to be accessable during high waters
  - They are nog sure if the hinterland is suited for these amounts of water?
  - Influence on other failure modes is not yet known (and our guidelines are all written for 1 l/m/s)
  - We are not used to it…

(3) Designing with higher overtopping discharges

- Not yet available in a probabilistic model consistent with the cumulative overload method, but there are rules…

Tabel B.1 Overzicht rekenwaarden voor het kritieke overslagdebiet

q_o (l/s/m)	Aanvullende eisen
0,1	• geen eisen
1	• gesloten of open zode op klei* • geen eisen aan objecten en overgangen • voldoende stabiliteit**
5	• Toepasbaar in twee mogelijke gevallen: – gesloten zode op klei* en H_{m0}<4 m **of** – open zode op klei* en H_{m0}< 2 m • taludhelling flauwer dan 1:2,3 • geen eisen aan objecten en overgangen op kruin • op talud geen objecten groter dan 0,15 x 0,15 m^2 en geen overgangen • voldoende stabiliteit**
10	• gesloten zode op klei • taludhelling flauwer dan 1:2,3 • objecten en overgangen op de kruin toegestaan (geldt niet in het bovenrivierengebied) • op talud geen objecten groter dan 0,15 x 0,15 m^2 en geen overgangen • H_{m0}<4 m • controle stabiliteit**
* Minimale gegarandeerde dikte van 0,4 m ** Controle of bij de rekenwaarde van het overslagdebiet leidt tot onaanvaardbare toename van de faalkans als gevolg van de geotechnische instabiliteit van de bekleding op het binnentalud of macrostabiliteit binnenwaarts. Dit kan leiden tot aanvullende eisen ten aanzien van kleilaagdikte, kleikwaliteit, aanbrengen drainage. taludhelling en dergelijke	

Knowledge gaps

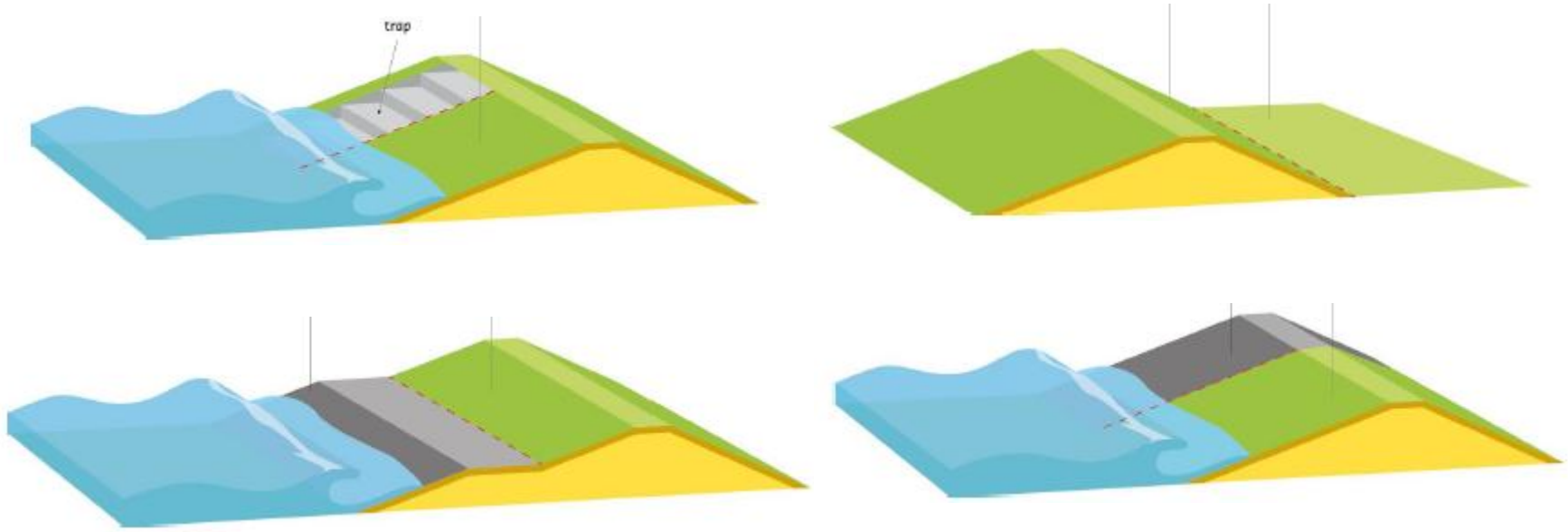
(4) Transitions

Grass revetments at Dutch dikes

- In last decades: research with simulators and Delta Flume
- Important conclusion: often grass itself is not weakest point but the transition is.

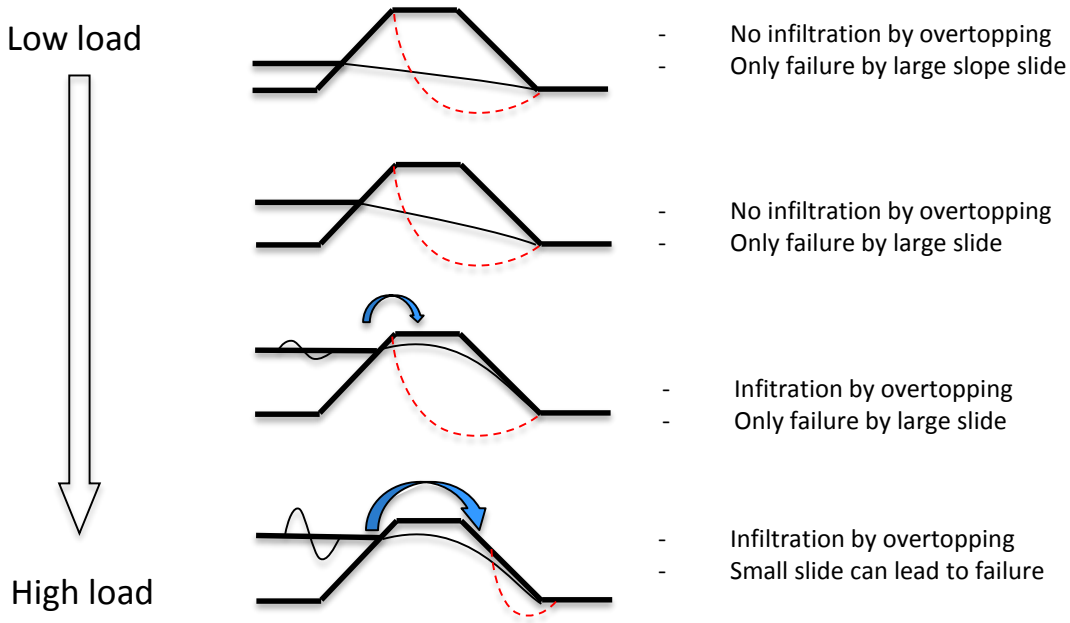
(4) Current project on transitions

Goal: verifying mitigating measures for (weak) transitions in grass slopes on revetments



(5) Other current research interests

- Outer slope: design level of hard revetments (and starting point of grass revetments)
- Ongoing research on transitions (This is important if many houses are built near or one the dike)
- How do we deal with **residual strength**?
- **Infiltration effects**
- Etc..



(5) Future research interest

- Transitions
- Further development of erosion model
- Interaction wave overtopping and phreatic levels (higher dischargers mean higher infiltration)

Compatibility with new safety standards

(levee breach)

→ ongoing erosion processes