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MODELLING WAVE OVERTOPPING FOR FLOOD DEFENCE RELIABILITY: THE OUTLINE OF A RESEARCH PROJECT

JORD J. WARMINK, VERA M. VAN BERGEIJK, WEIQIU CHEN,

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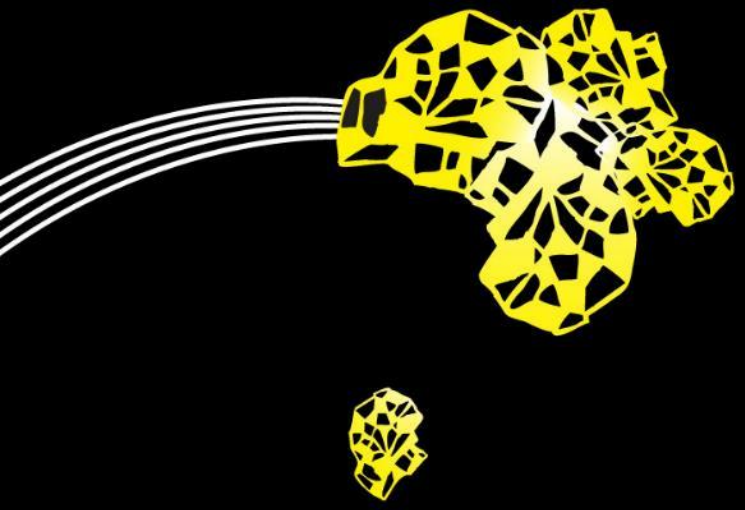

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MODELLING WAVE OVERTOPPING FOR EMBANKMENT STABILITY: PRELIMINARY RESULTS OF A RESEARCH PROJECT

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INTRODUCTION
GRASS COVERED EMBANKMENTS

- Present worldwide
- Grass cover is first layer of protection against wave overtopping

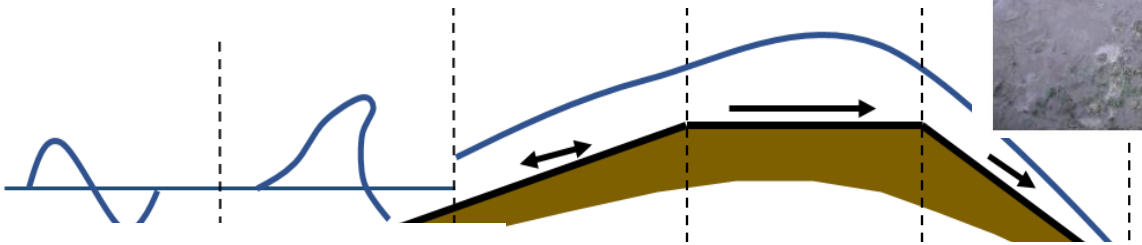

Grass covered levee breach (© CA dept. Water Resources)

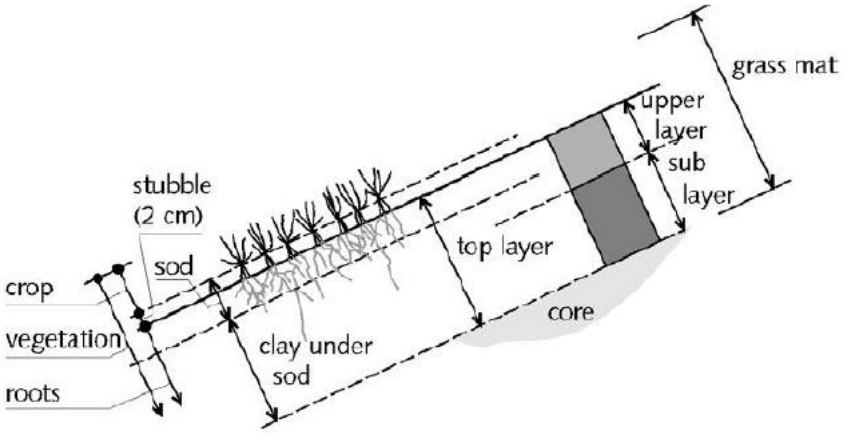

Flower-rich dike vegetation (© Cyril Liebrand)

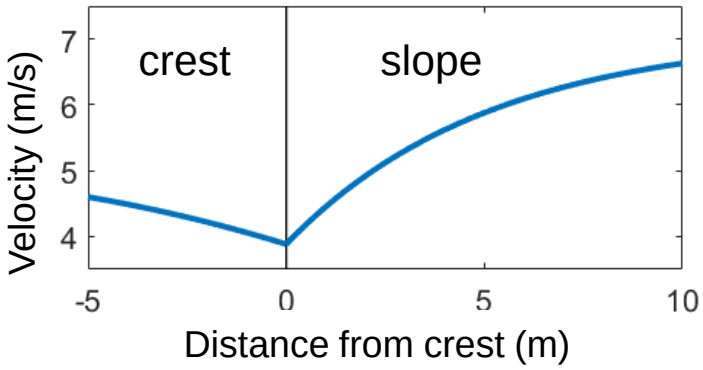

Grass covered levee, Arkensas (© FEMA)

INTRODUCTION
EROSION OF GRASS COVERED EMBANKMENTS

- Erosion of grass cover initiated by overtopping flow (crest & land-side slope)
- Failure of top-layer
  - Rooted upper-layer & substrate sub-layer







INTRODUCTION
EROSION OF GRASS COVERED EMBANKMENTS

Objectives:

- Study the effect of transitions in embankment covers on wave overtopping flow and erosion for dike stability
- Simulate embankment-cover erosion & wave overtopping flow

Transition type	Model parameter	Examples	
Cover type	Friction coefficient f_F	High → low	
		Low → high	
Inclination	Slope angle φ	Convex	
		Concave	

INTRODUCTION

EROSION OF GRASS COVERED EMBANKMENTS

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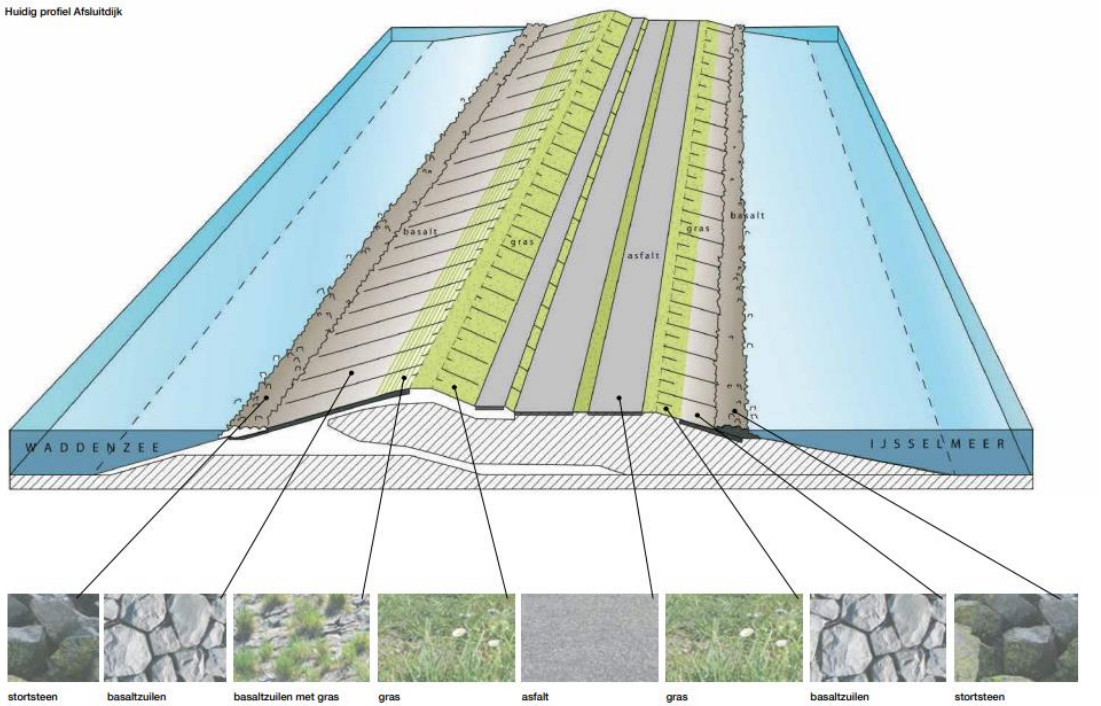

INTRODUCTION
EROSION OF GRASS COVERED EMBANKMENTS

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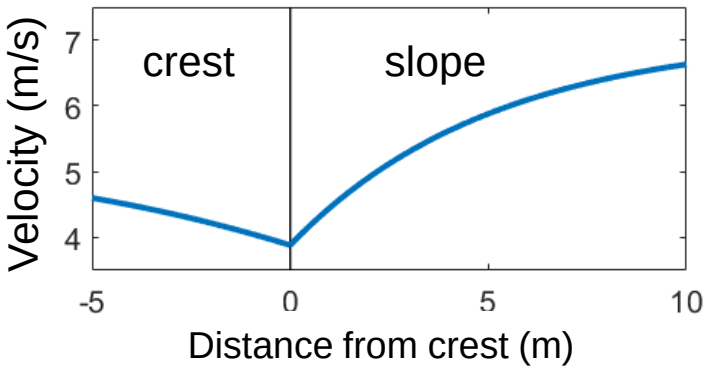
- Outline of this talk:
  1. Idealized model of wave overtopping flow
  2. Detailed numerical model results
  3. Ongoing and further work

METHOD 1

IDEALISED MODEL (PHD: VERA VAN BERGEIJK, V.M.VANBERGEIJK@UTWENTE.NL)

- Simple analytical model based on Van Gent (2002) and Schuttrumpf & Oumeraci (2005).
- INPUT: Flow velocity ($u_{0;\,2\%}$) and Layer thickness ($h_{0;\,2\%}$) at seaward point of crest.
- OUTPUT: Flow velocity u(x) and layer thickness h(x) along crest and landward slope.
- Assume continuity of discharge
- Vary slope and roughness



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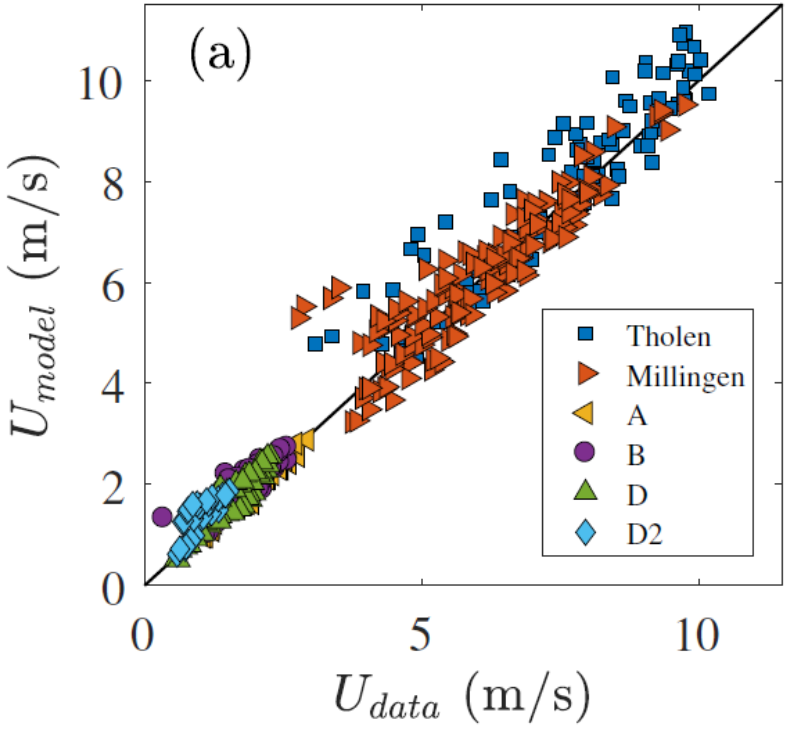
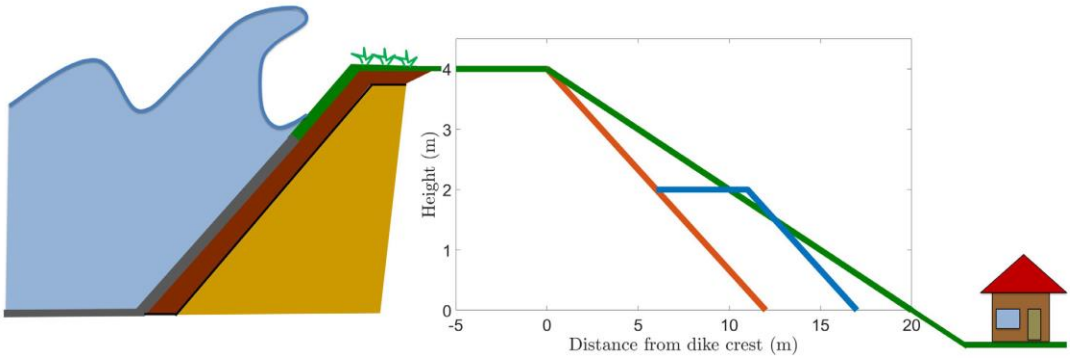
- OUTPUT: Flow velocity u(x) an landward slope.
- Assume continuity of discharge
- Model validated for 500 flume/field observations

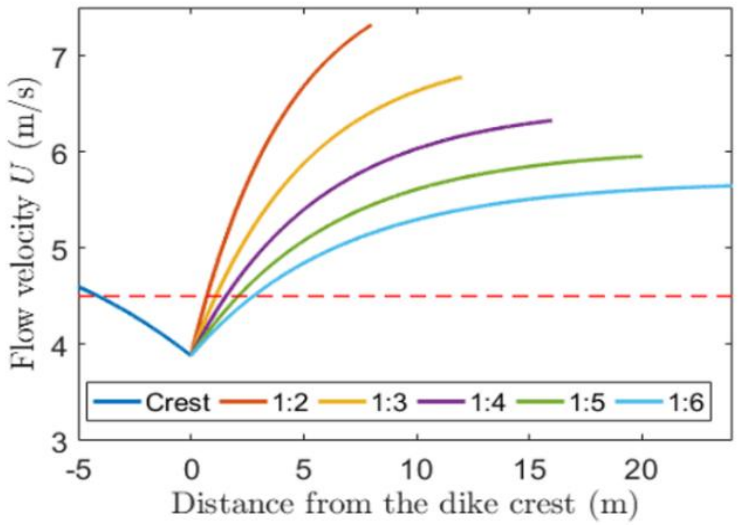


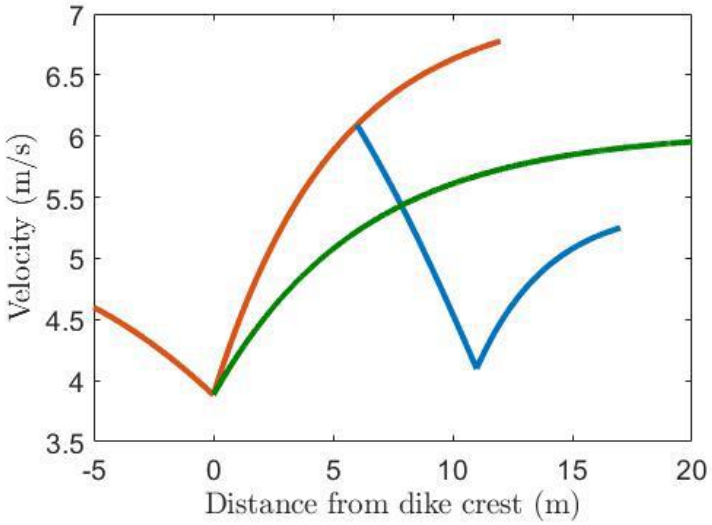
METHOD 1

IDEALISED MODEL (PHD: VERA VAN BERGEIJK, V.M.VANBERGEIJK@UTWENTE.NL)

- Simulate velocity along crest and slope
- Screening tool for effects of shape and roughness of slope



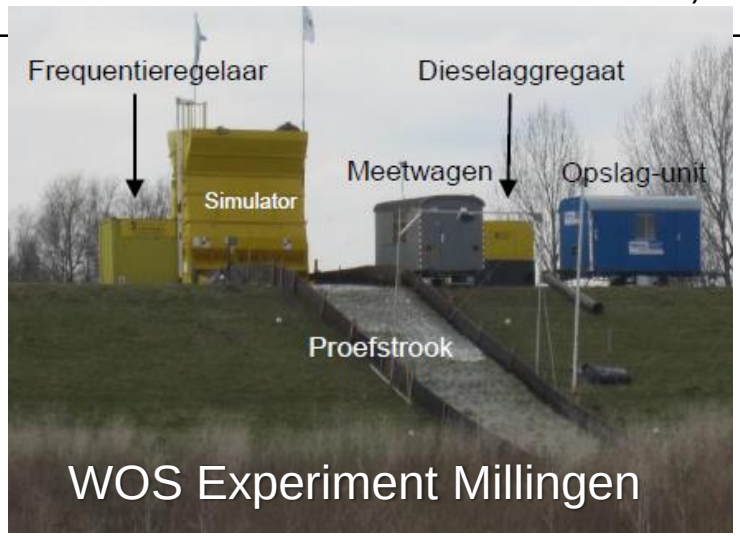


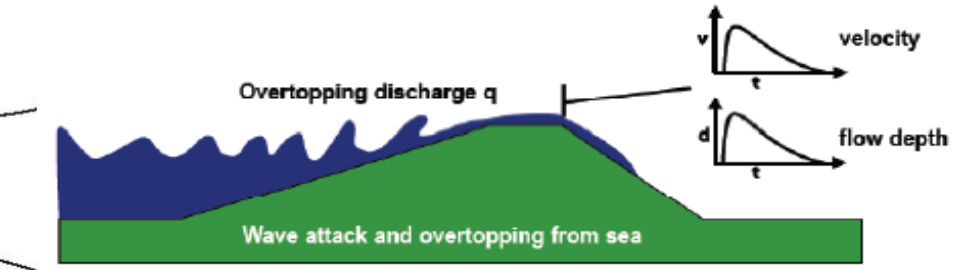


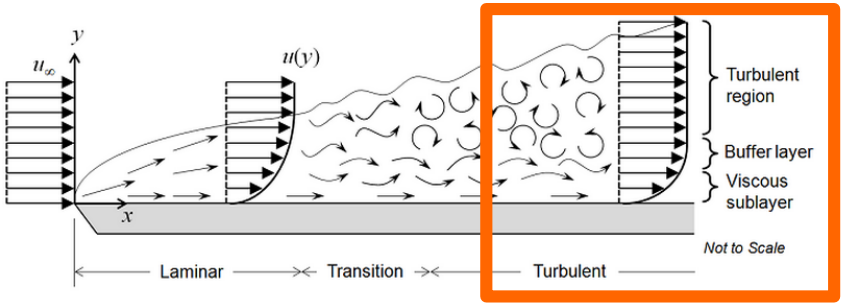
METHOD 2

NUMERICAL HYDRODYNAMIC MODEL (BOMERS ET AL. 2018; AGUILAR ET AL. 2018)

- Setting-up the model







RANS (K-epsilon)

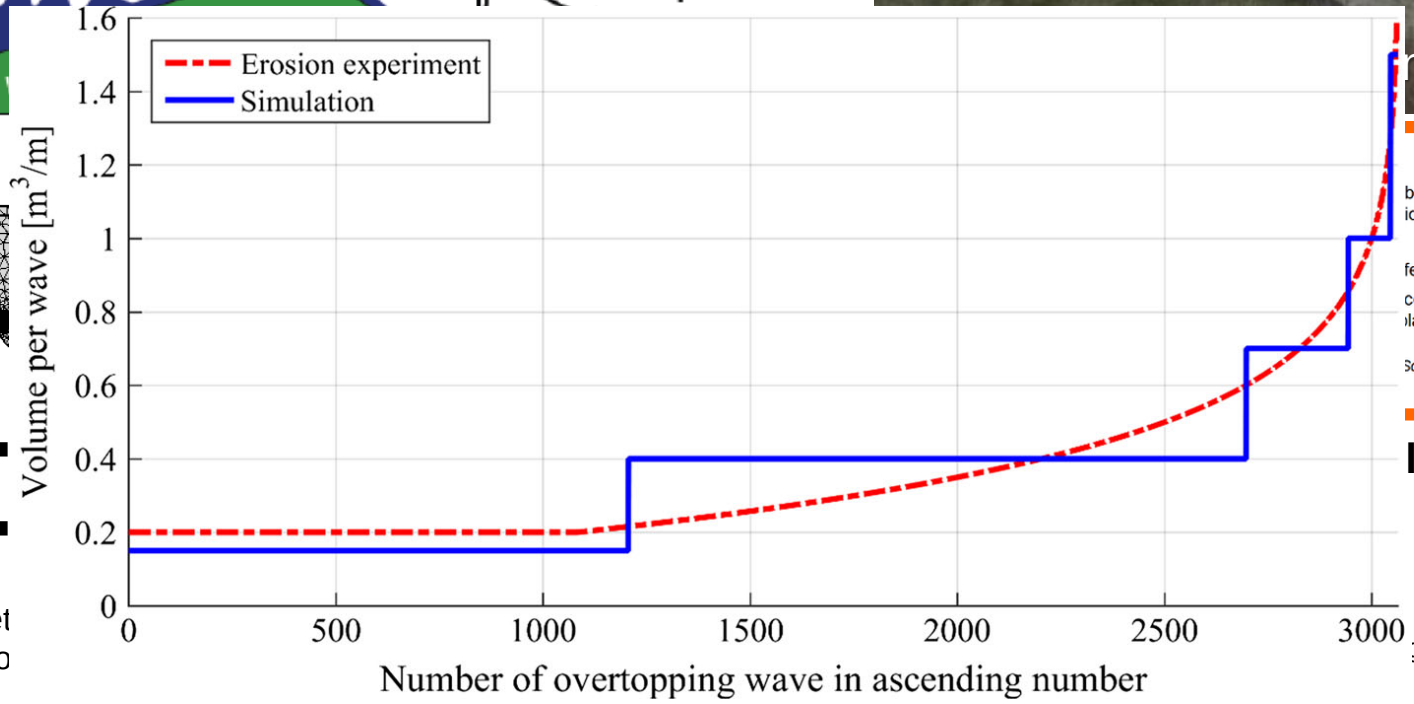
- CFD finite element model
- 2-phase flow: RANS (k-epsilon)

- Bomers et al. (2018): Nat Hazards 93:1. DOI: 10.1007/s11069-018-3287-y
- Aguilar-Lopez et al. (2018): J. Mar. Sci. Eng. 6:74; DOI: 10.3390/jmse6030074

METHOD 2

NUMERICAL HYDRODYNAMIC MODEL (BOMERS ET AL. 2018; AGUILAR ET AL. 2018)

- Input 5 volumes/waves



- Bomers et
- Aguilar-Lo

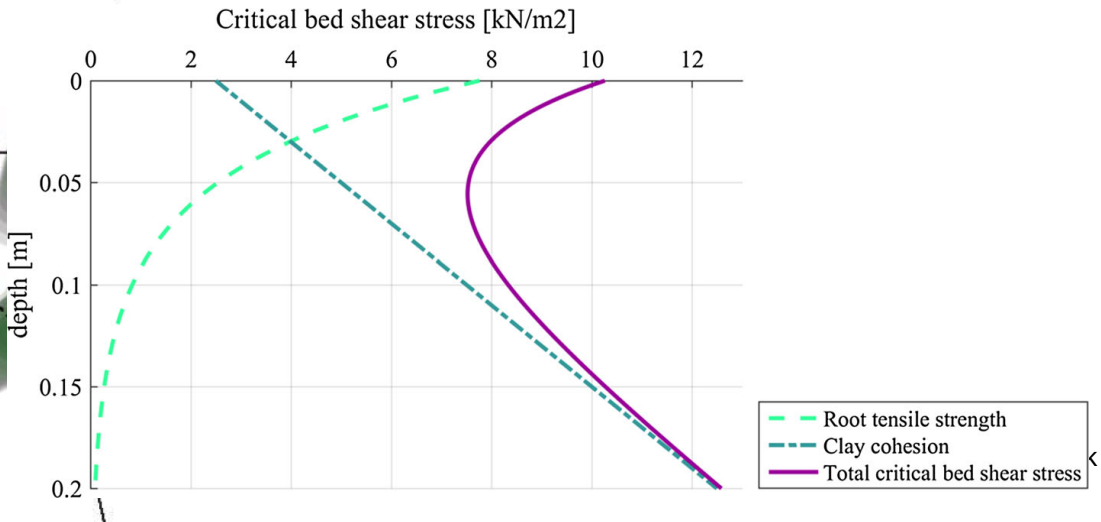
METHOD 2

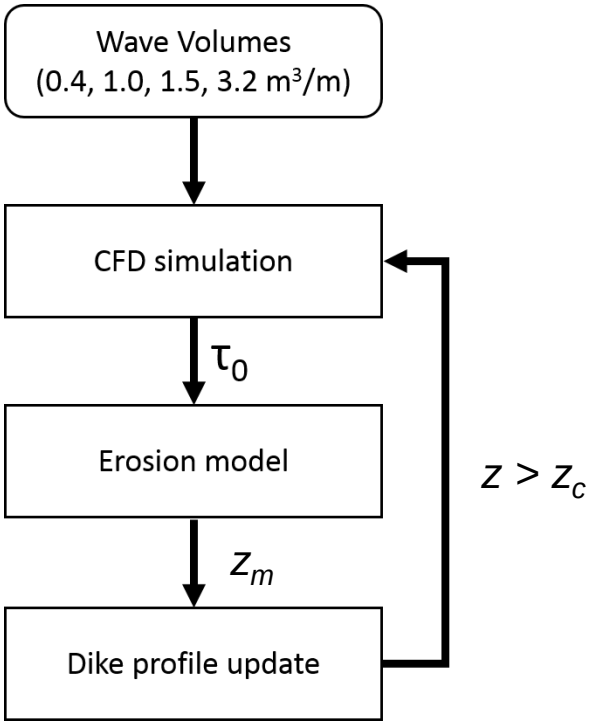
HYDRODYNAMIC-EROSION MODEL (BOMERS ET AL. 2018; AGUILAR ET AL. 2018)

- Erosion model based on shear stress, τ (based on Hoffmans; Valk, 2009)
- z_m is erosion depth:

$$z_m(x,t,d) = -\frac{[\omega\tau_0(x,t) - \tau_c(d)]\,T_0(x,t)}{E_{soil}(d)}$$

T_0: overtopping time
ω : turbulence factor
E_{soil} : strength parameter

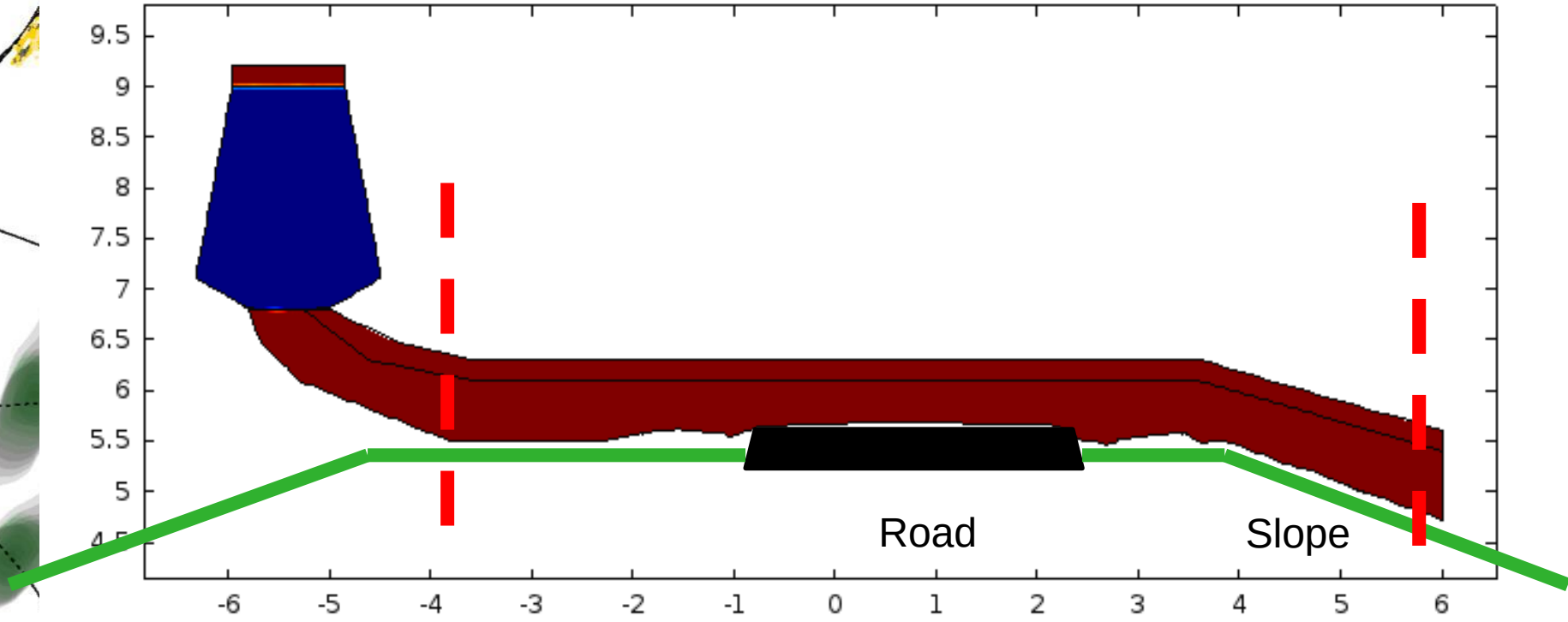




RESULTS NUMERICAL MODEL

HYDRODYNAMIC MODEL

- Real scale model (U_max 6m/s; Fr = 2 - 10 [-])
- Shows realistic flow field, needs validation

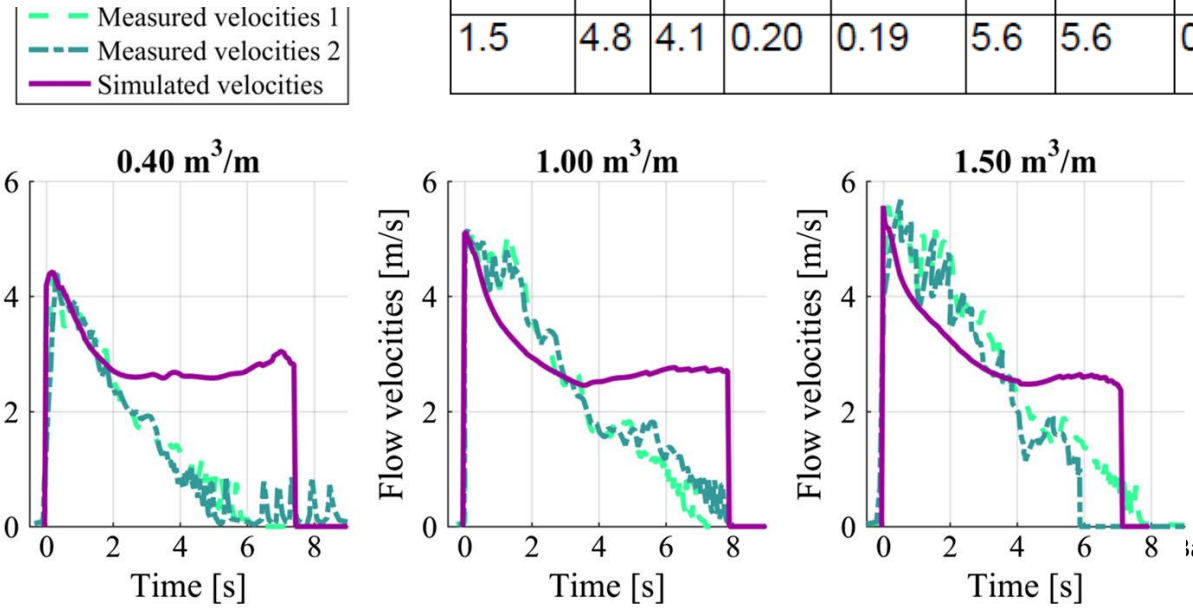


RESULTS NUMERICAL MODEL

VALIDATION HYDRODYNAMIC MODEL

- Velocity (u) and depth (h) measurements at crest and top slope

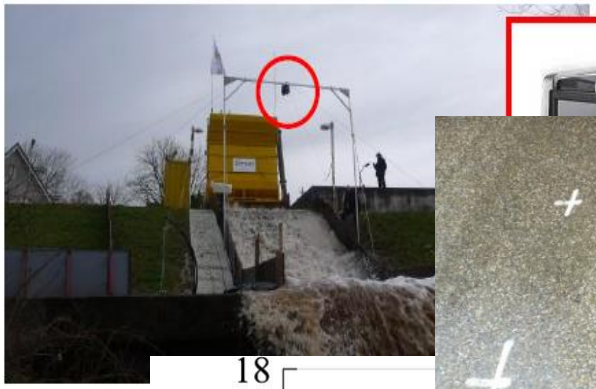
V_{wave} (m^3/m)	Location outlet				Location slope			
	u_{obs}	u_{sim}	h_{obs}	h_{sim}	u_{obs}	u_{sim}	h_{obs}	h_{sim}
0.4	3.4	3.0	0.13	0.1	4.5	4.4	0.02	0.03
1.0	4.6	3.8	0.18	0.16	5.1	5.1	0.06	0.10
1.5	4.8	4.1	0.20	0.19	5.6	5.6	0.10	0.13

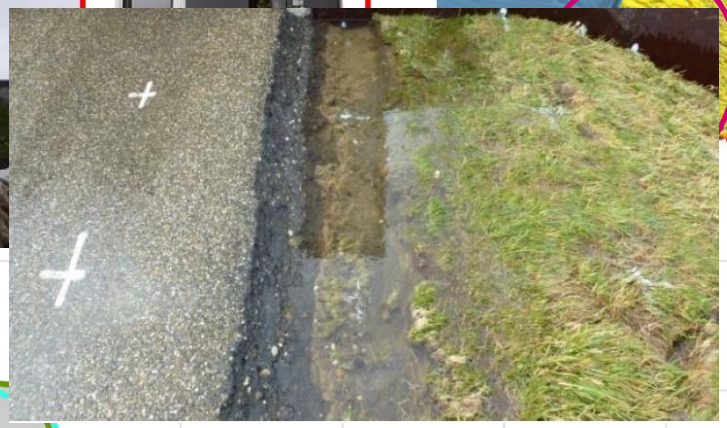


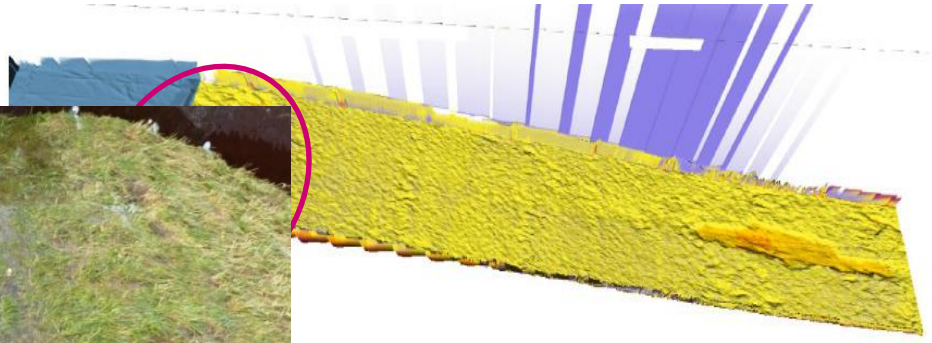
RESULTS NUMERICAL MODEL

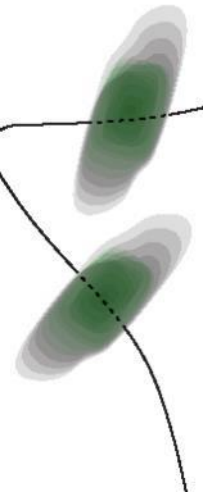
VALIDATION COUPLED HYDRODYNAMIC-EROSION MODEL

- Erosion depth validation of landward slope







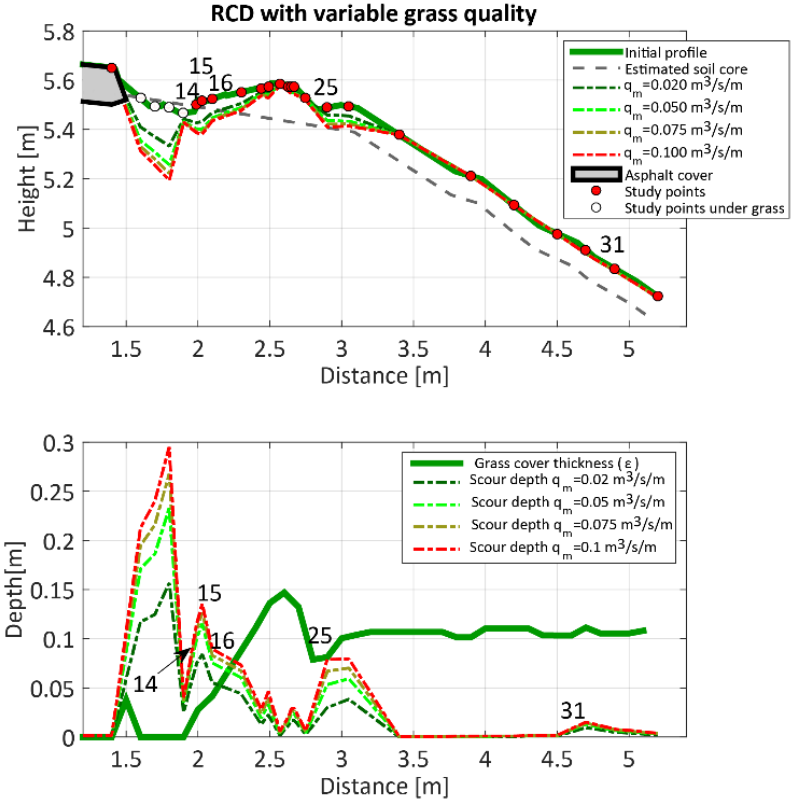


RESULTS NUMERICAL MODEL

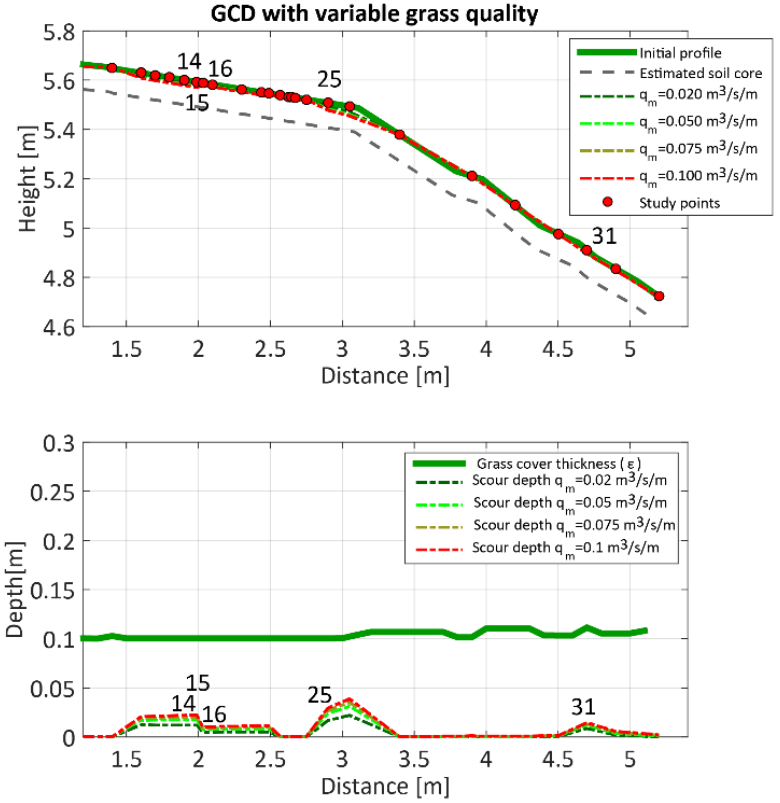
APPLICATION: EFFECT OF A ROAD ON EMBANKMENT COVER EROSION

- A road changes the location of maximum erosion

With road



Without road



DISCUSSION AND FUTURE WORK

EFFECT OF TRANSITIONS ON EMBANKMENT COVER EROSION

- Numerical model is promising, but requires further validation
  - High quality flow, soil and erosion data are needed
  - More cases needed: vegetation types, soil types, transitions
- Erosion model works surprisingly well
  - But, need to include other grass/soil failure-mechanisms

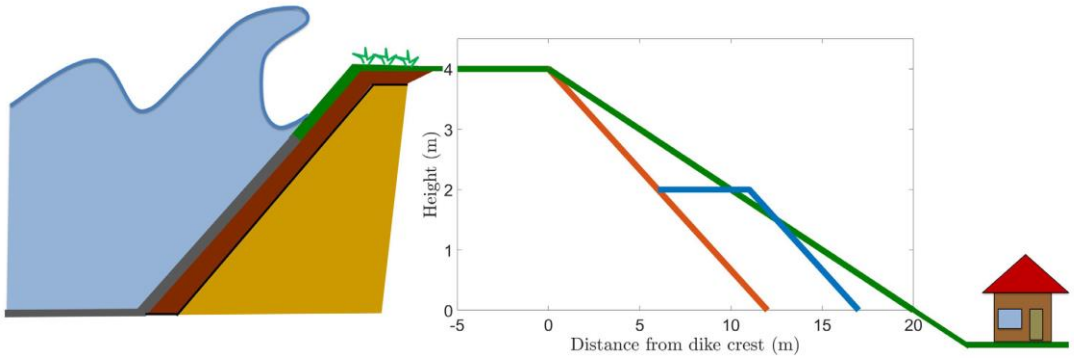
Flower-rich dike vegetation (© Liebrand)

DISCUSSION AND FUTURE WORK

ONGOING RESEARCH

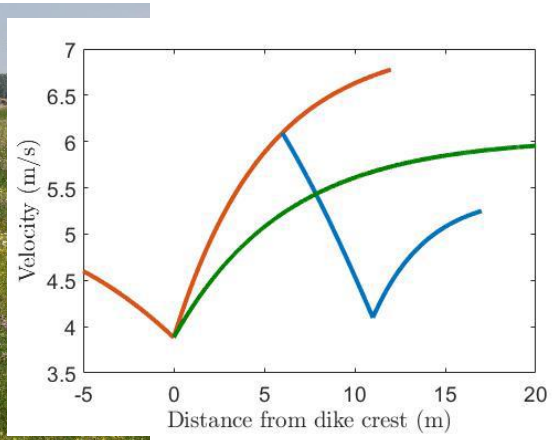
PhD, Vera van Bergeijk

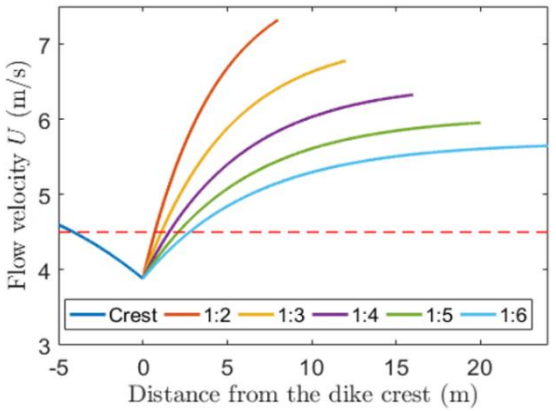
- Effect of transitions on overtopping erosion
- Develop OpenFoam detailed numerical model



Idealised model, velocity only.

Flower-rich dike vegetation (© Cyril Liebrand)

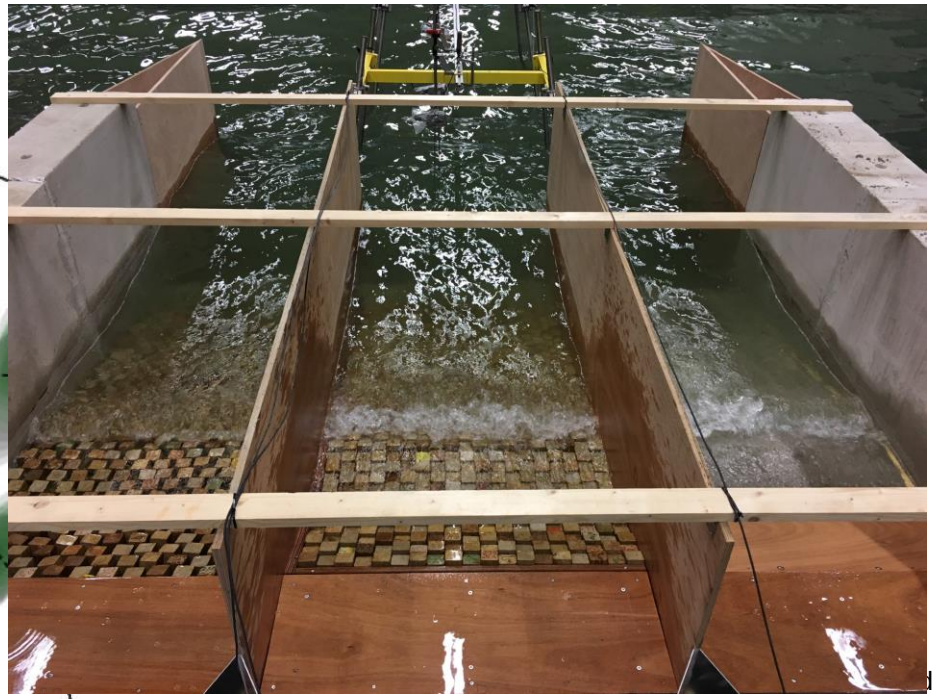


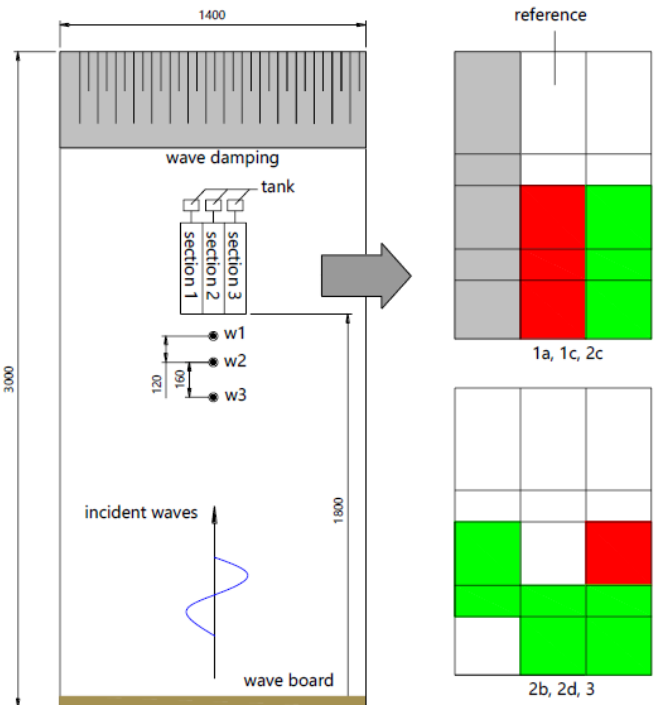


DISCUSSION AND FUTURE WORK
ONGOING RESEARCH

PhD, Weiqiu Chen, UTwente/Deltares (M. van Gent)

- New laboratory tests @Deltares: combined effect of roughness (γ_f) berm (γ_b) on wave overtopping discharge → improve overtopping equation.

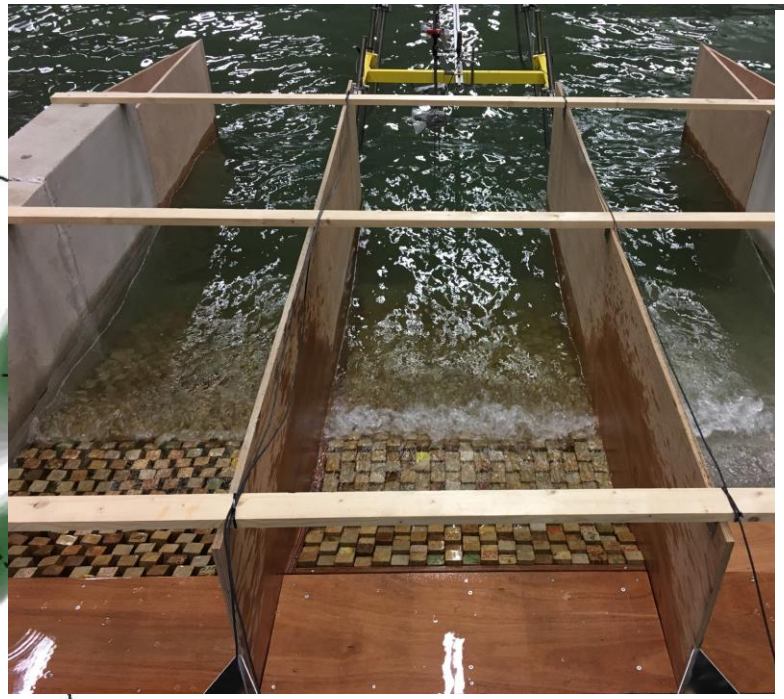


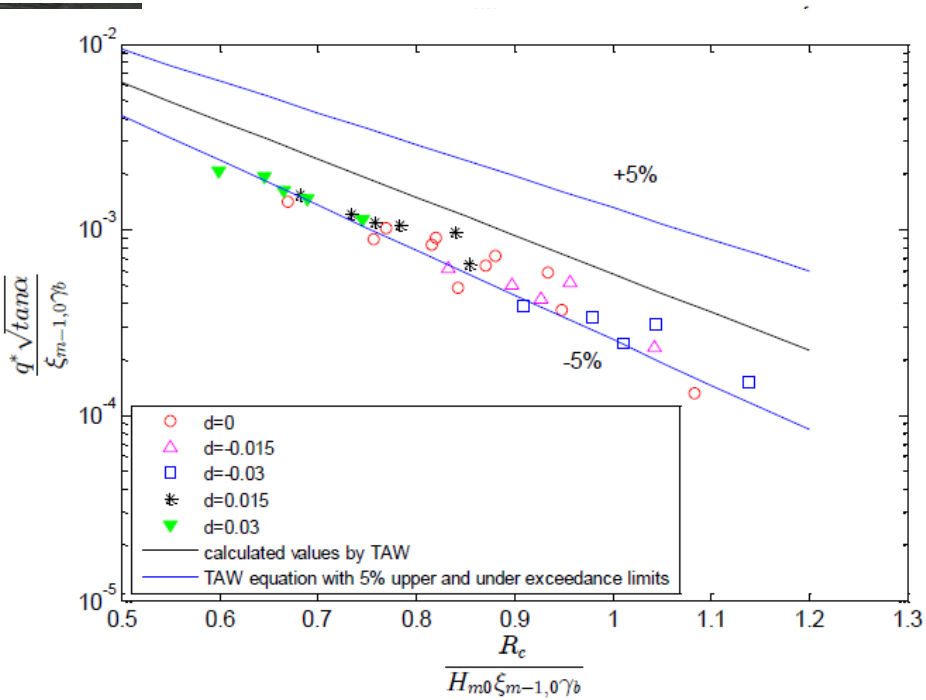


DISCUSSION AND FUTURE WORK

ONGOING RESEARCH

- Preliminary results show that TAW/EurOtop equation overestimates overtopping discharge
- PhD, Weiqiu Chen, UTwente/Deltares (M. van Gent)

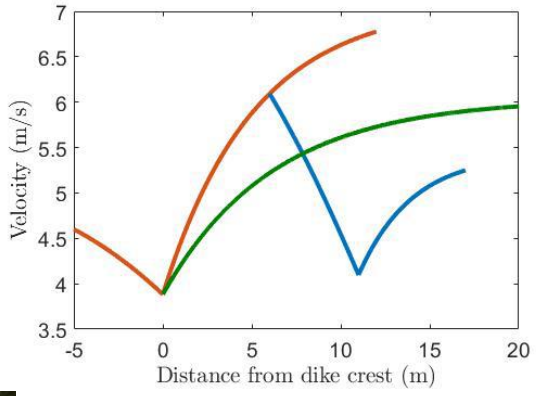




TO CONCLUDE

MODELLING WAVE OVERTOPPING FOR EMBANKMENT STABILITY

- Idealized model provides fast predictions of effect of (longitudinal) transitions
- Numerical model is able to simulate grass-cover erosion due to overtopping waves, but ....
- Research is ongoing, opportunities to collaborate: exchange experimental data, models, expertise.

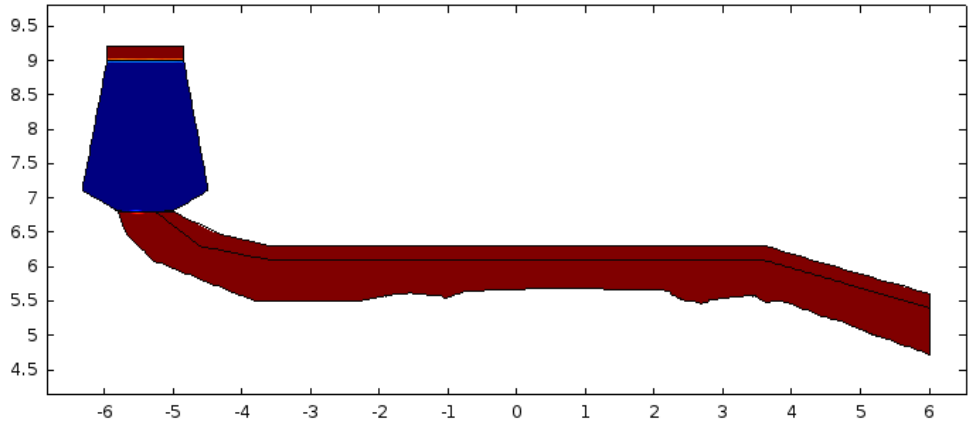



Flower-rich dike vegetation (© Cyril Lebrand)

THANK YOU FOR YOUR ATTENTION

MODELLING WAVE OVERTOPPING FOR FLOOD DEFENCE RELIABILITY

- Have a nice paper? Submit to special issue “Resilient Flood Defences” of Journal Marine Science and Engineering. Fast review guaranteed.
- http://www.mdpi.com/journal/jmse/special_issues/Resilient_Flood_Defences
- Aguilar-Lopez, J.P. Warmink, J.J. et al. (2018). Failure of grass covered flood defences due to wave overtopping. J. Mar.Sci.Eng. https://doi.org/10.3390/jmse6030074
- Bomers, A., Aguilar Lopez, J.P., Warmink, J.J. et al. Modelling effects of an asphalt road at a dike crest on dike cover erosion onset during wave overtopping Nat Hazards (2018). https://doi.org/10.1007/s11069-018-3287-y



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