1. Introduction

Joint Industry Project (JIP) CoastalFoam

- Development of OpenFOAM (CFD)
- status update on work for permeable coastal structures

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- status update on work for permeable coastal structures

Toe structures

- Protect armour layer against scour
- Support armour layer

photo: Van Gent & Van der Werf (2014)

1. Introduction

Joint Industry Project (JIP) CoastalFoam

- Development of OpenFOAM for permeable coastal structures

Toe structures

- Support armour layer
- Protect armour layer against scour

Questions

- Are filter layers or geotextiles needed underneath the toe?
- ... or can it be placed directly on sand?

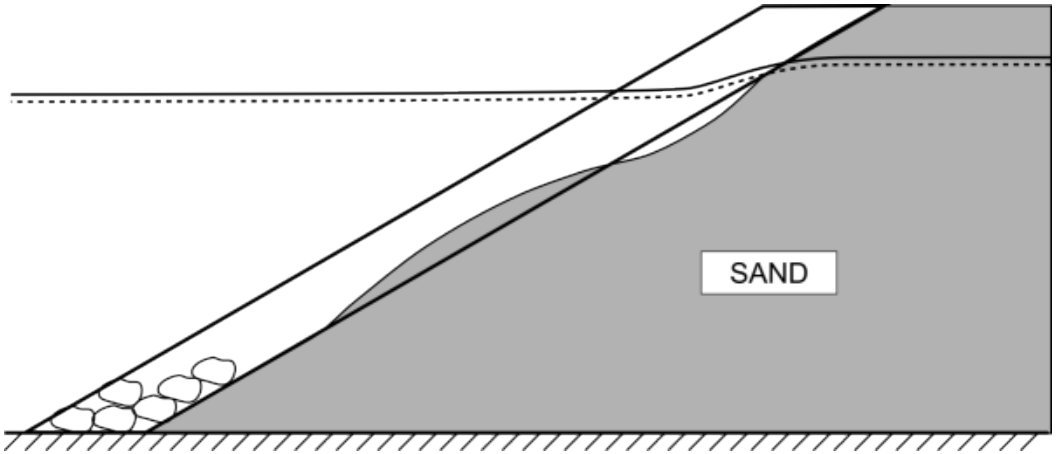
1. Introduction

Objective

- Extend OpenFOAM model (CFD)
  - based on the previous work for open filters
- Apply extended model to toe structures

2. Numerical model extension

- Jacobsen et al. (2017) implemented erosion/deposition inside filters in OpenFOAM
  - to be able to model open filters
  - also within JIP CoastalFoam
  - assumption: bed-load type sediment transport formulation



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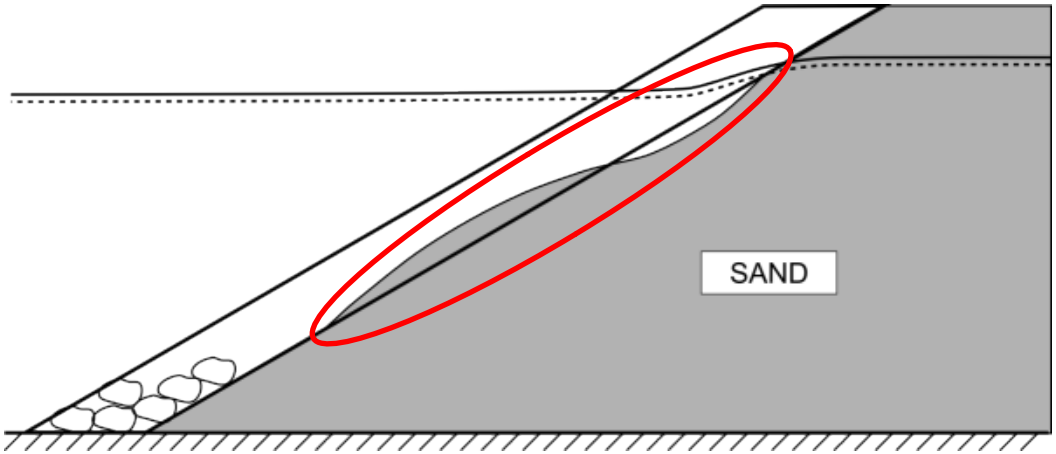
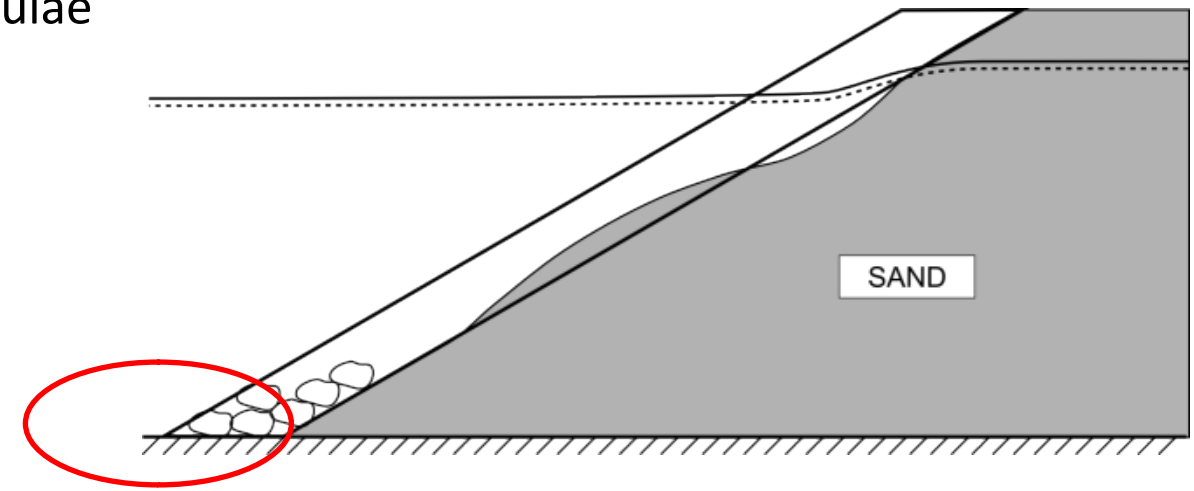


2. Numerical model extension

- Jacobsen et al. (2017) implemented erosion/deposition inside filters in OpenFOAM

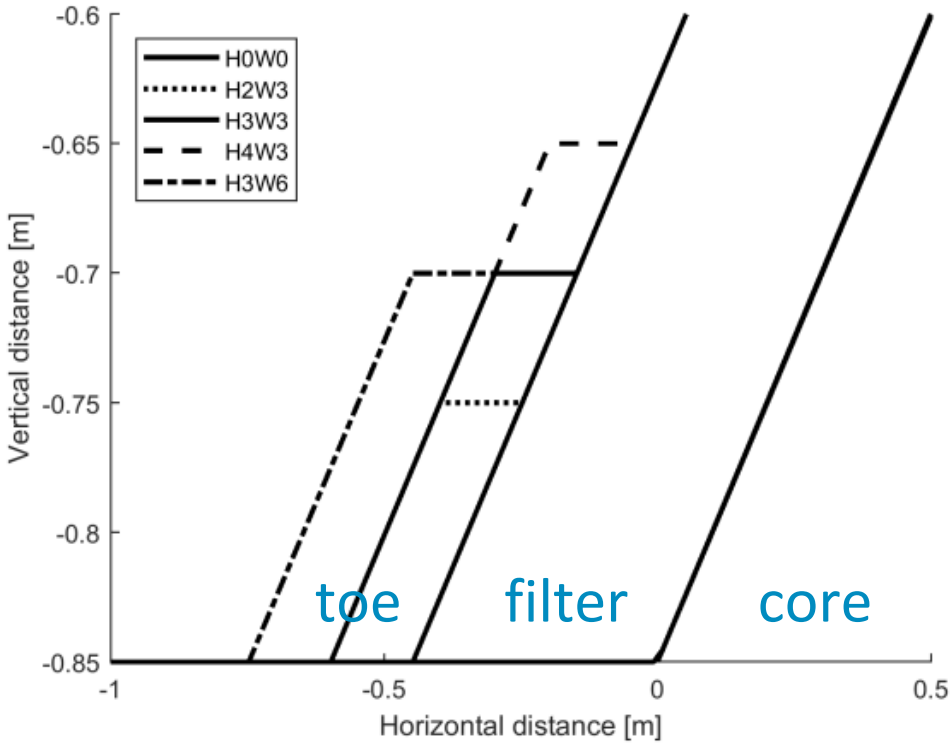
- Implementation has been extended:
  - allowing exchange of sediment between porous layers and ‘outside’
  - each layer has own sediment transport equation
  - active layer depends on bed level position (relative to porous layers)
  - on interfaces between layers: sediment transport is weighted between different layers/formulae



3. Toe structures – model setup

Structure

- 1V:2H slope
- Impermeable core
- Filter & toe D_{n50}= 5 cm
- Width 3/6 D_{n50}
- Height 2/3/4 D_{n50}
- Stones toe & filter are fixed
- Typical flume dimensions



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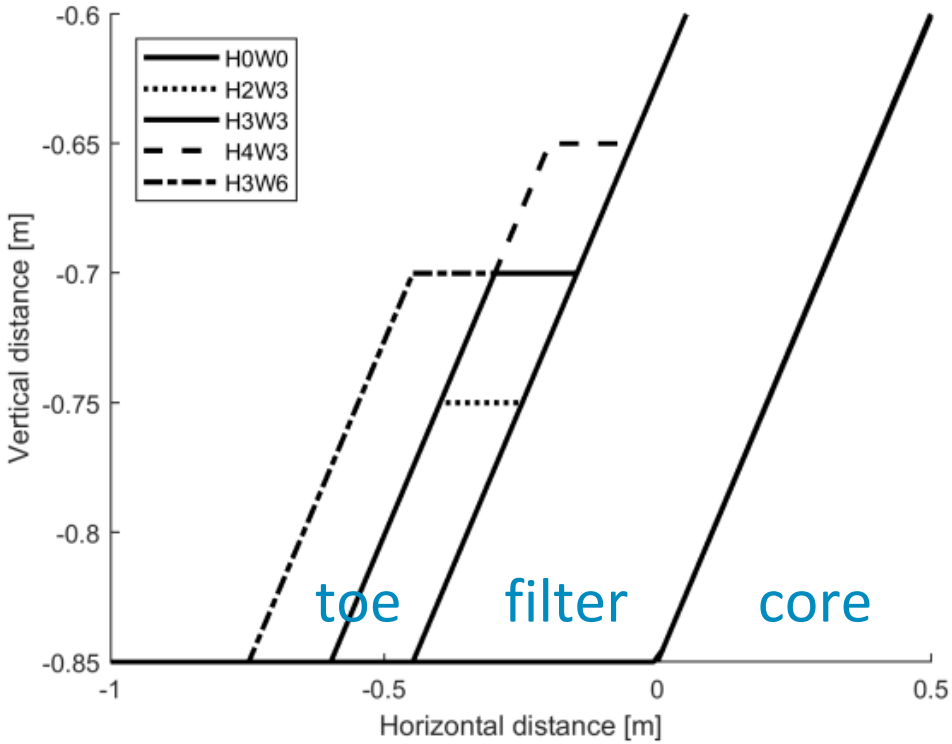

Model settings

- 500 waves
- Morphological acceleration factor (morfac) 5
- Represents 2500 waves of morphological development

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3. Toe structures – model setup

Toe	h [m]	H_s [m]	T_p [s]	$s_{0,p}$ [%]
H0W0	0.50	0.15	4.59	1.5
H0W0	0.85	0.15	3.62	1.5
H2W3	0.50	0.15	4.59	1.5
H2W3	0.85	0.15	3.62	1.5
H3W3	0.50	0.15	4.59	1.5
H3W3	0.50	0.15	2.83	2.5
H3W3	0.50	0.15	1.87	4.0
H3W3	0.85	0.15	3.62	1.5
H3W3	0.85	0.15	2.32	2.5
H3W3	0.85	0.15	1.64	4.0
H4W3	0.50	0.15	4.59	1.5
H4W3	0.85	0.15	3.62	1.5
H3W6	0.50	0.15	4.59	1.5
H3W6	0.85	0.15	3.62	1.5

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Toe	h [m]	H_s [m]	T_p [s]	$s_{0,p}$ [%]	
H0W0	0.50	0.15	4.59	1.5	No toe structure
H0W0	0.85	0.15	3.62	1.5	
H2W3	0.50	0.15	4.59	1.5	
H2W3	0.85	0.15	3.62	1.5	
H3W3	0.50	0.15	4.59	1.5	Base configuration
H3W3	0.50	0.15	2.83	2.5	
H3W3	0.50	0.15	1.87	4.0	
H3W3	0.85	0.15	3.62	1.5	
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H3W6	0.50	0.15	4.59	1.5
H3W6	0.85	0.15	3.62	1.5

4. Results – Hydraulic load

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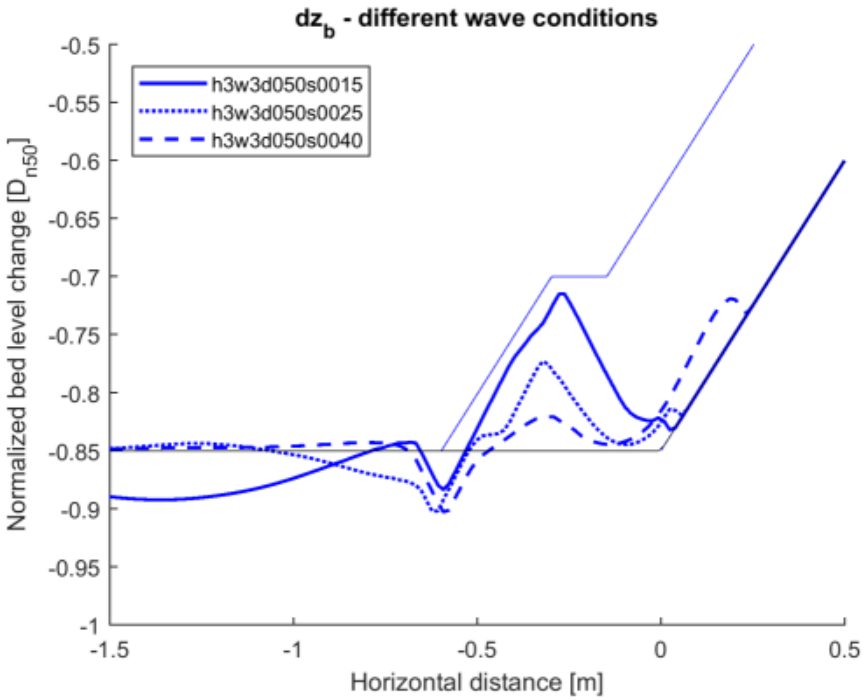
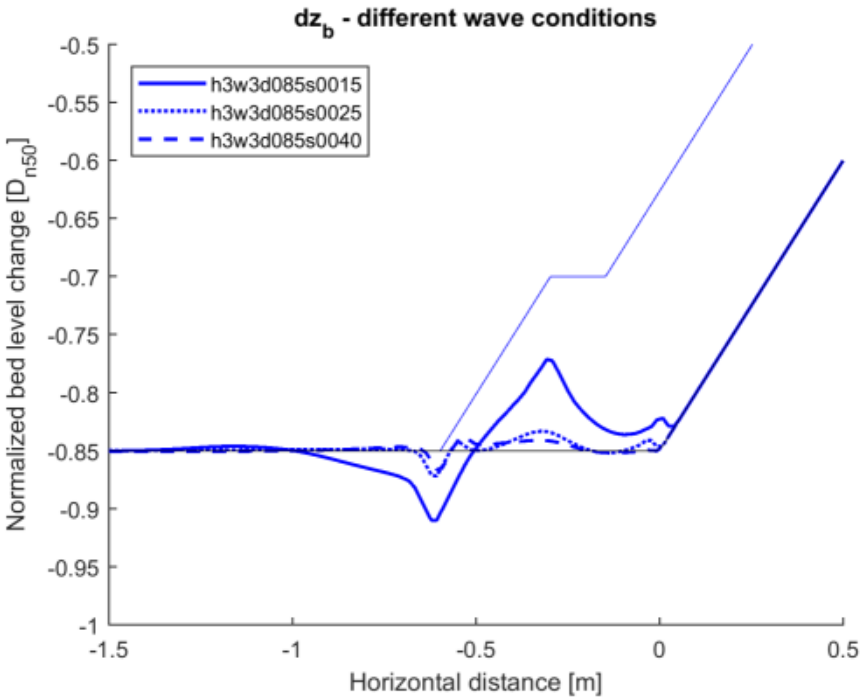
0.50 m depth



0.85 m depth



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4. Results – Hydraulic load

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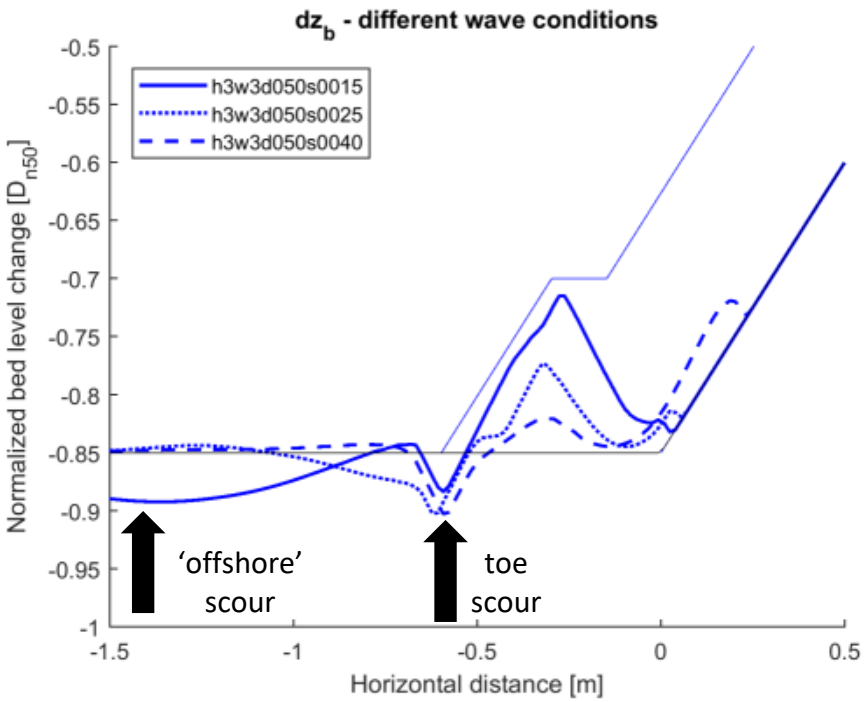

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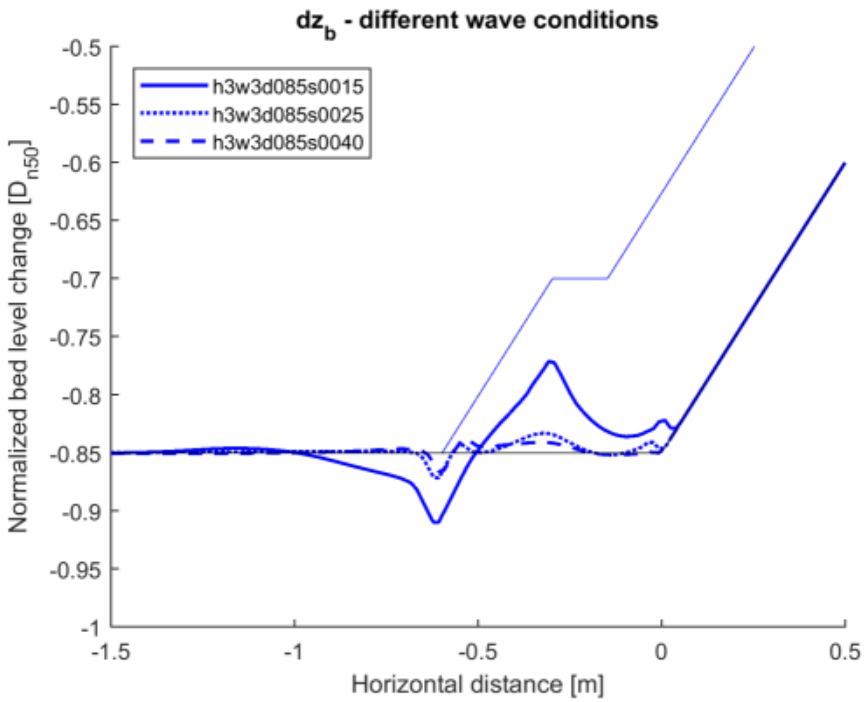
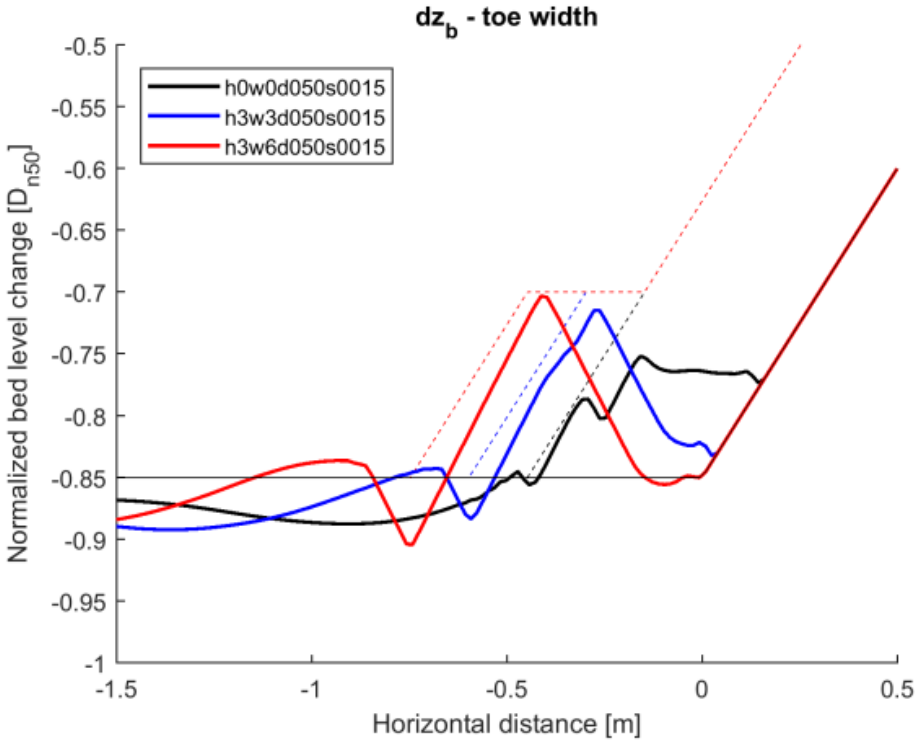


- Smallest steepness/water depth → most morphological change
- Infilling inside structure

4. Results – Toe width

0.50 m depth



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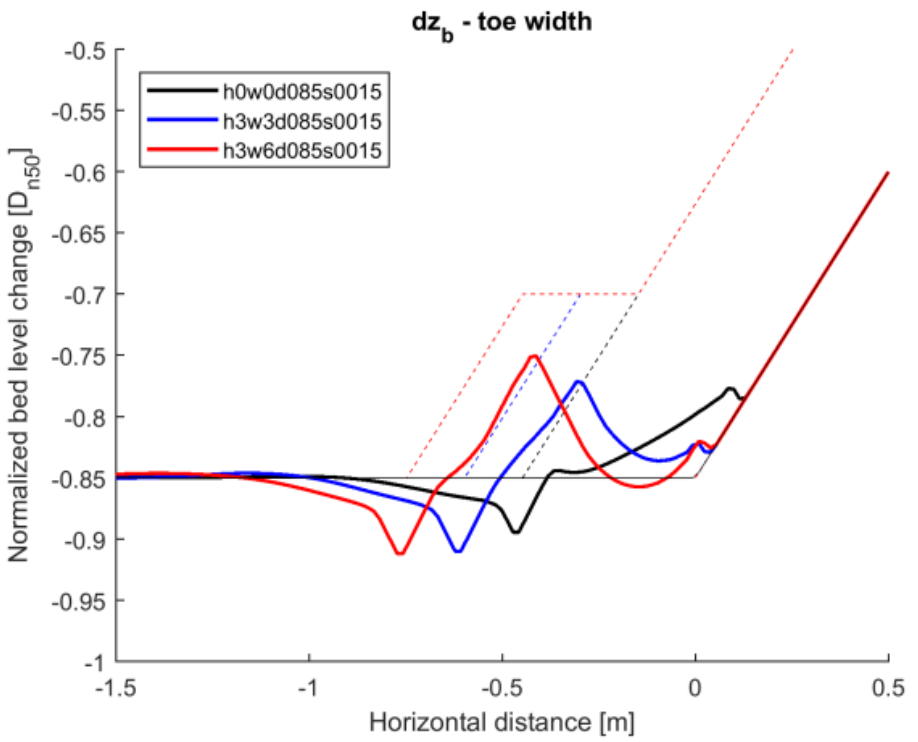

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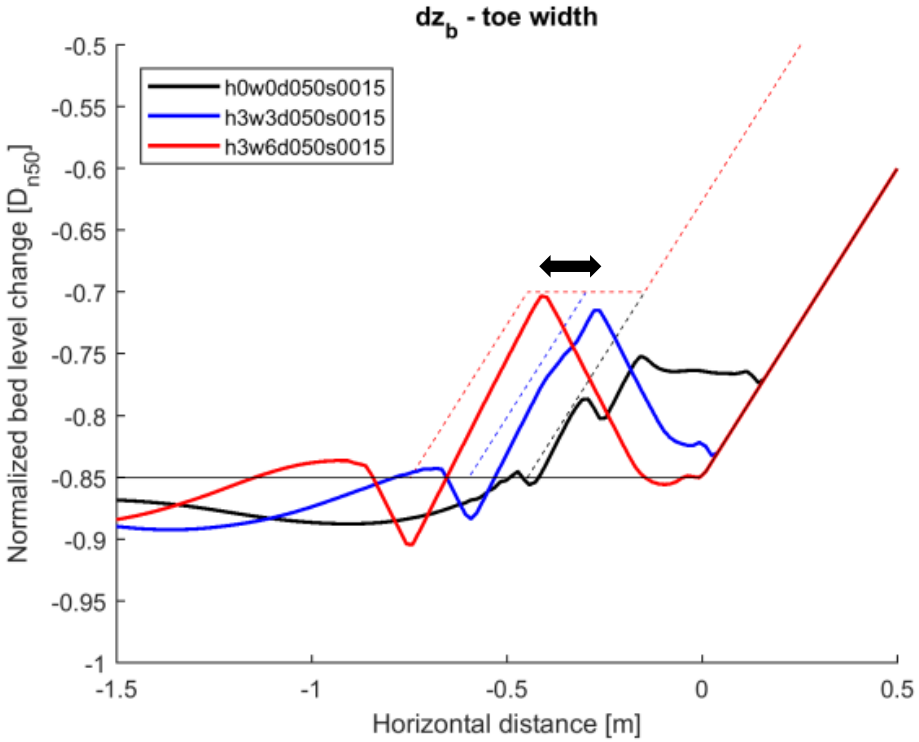

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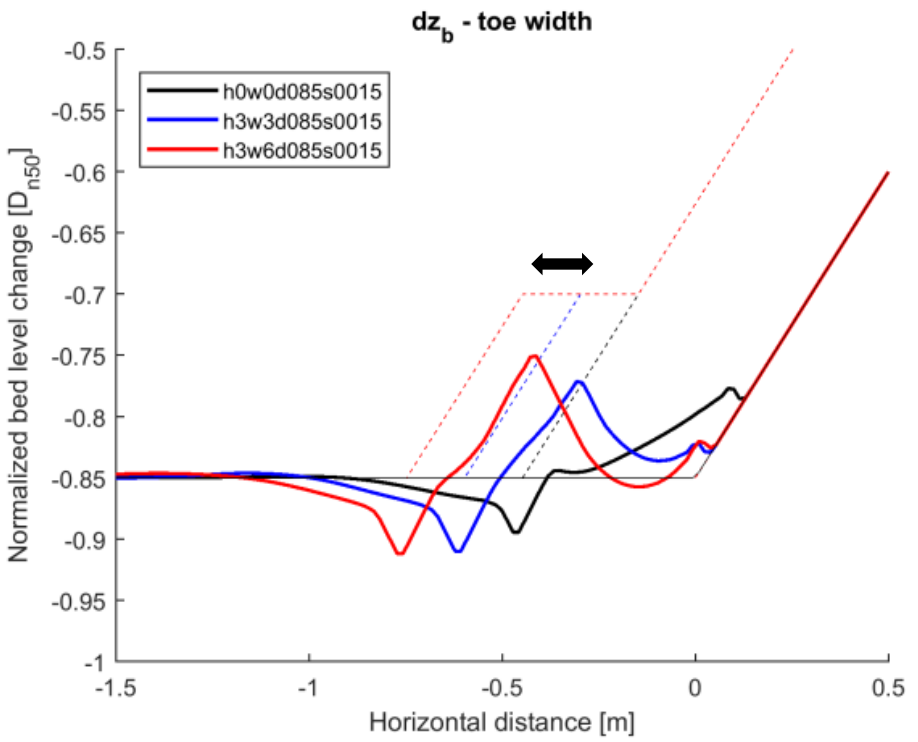
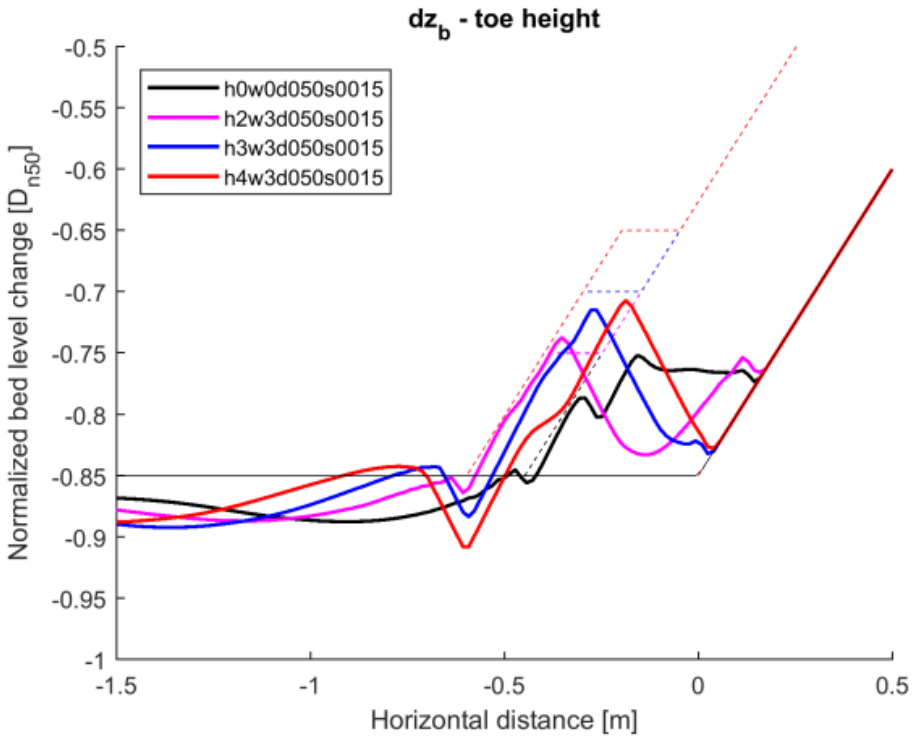


- Infilling inside structure – follows outer crest of toe
- Deeper toe scour for larger toe width (shallow water)

4. Results – Toe height

0.50 m depth



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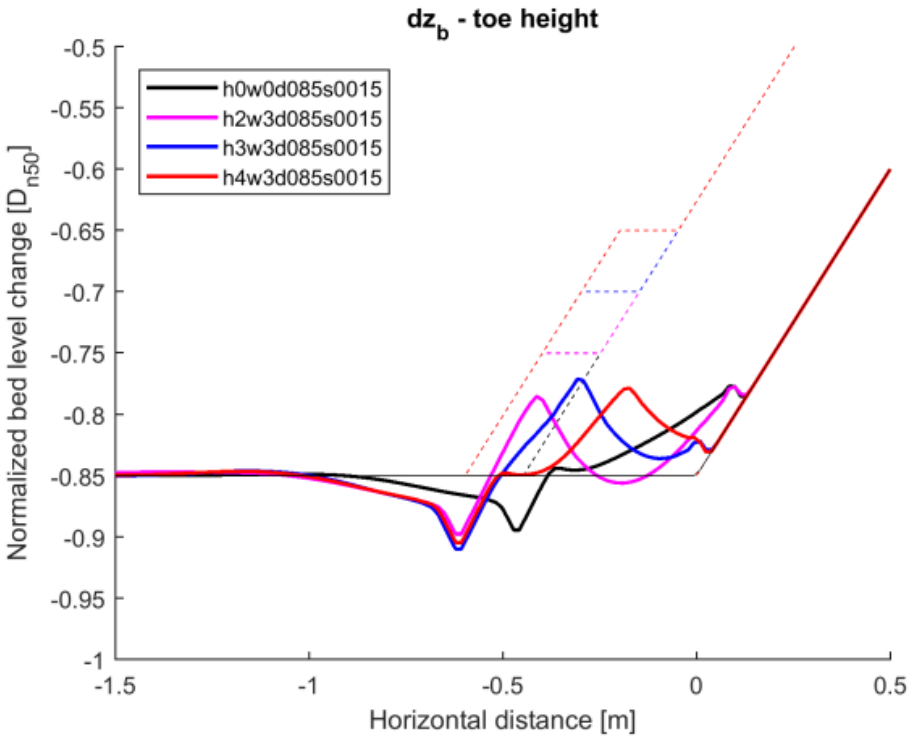

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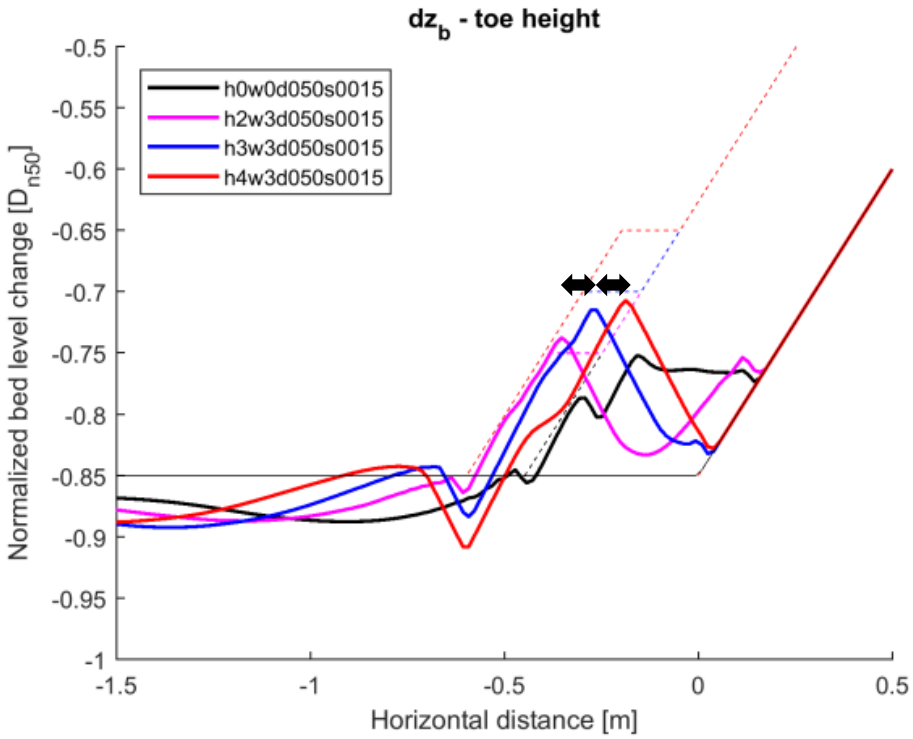

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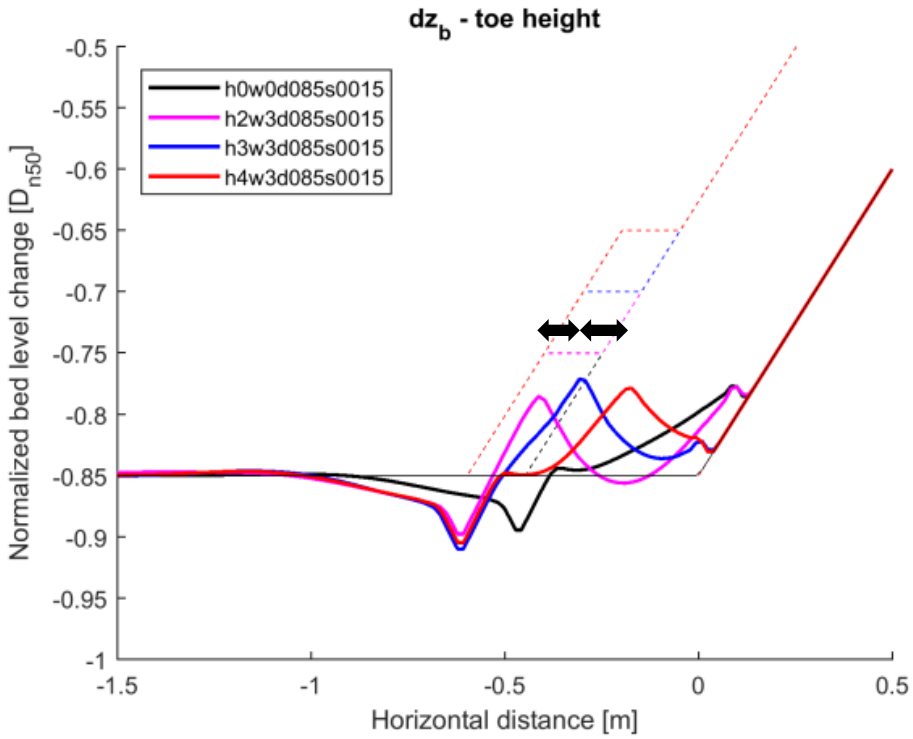

- Infilling inside structure – follows outer crest of toe
- Toe scour hole larger for higher toe (shallow water)

4. Results – scour hole development

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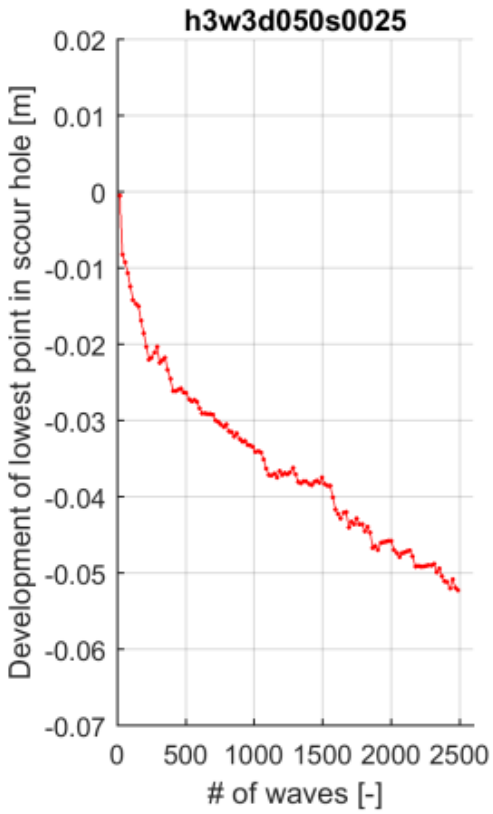
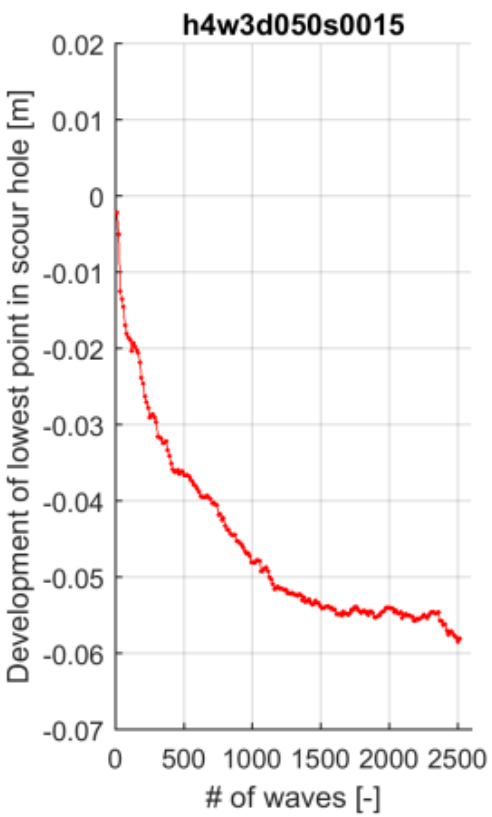
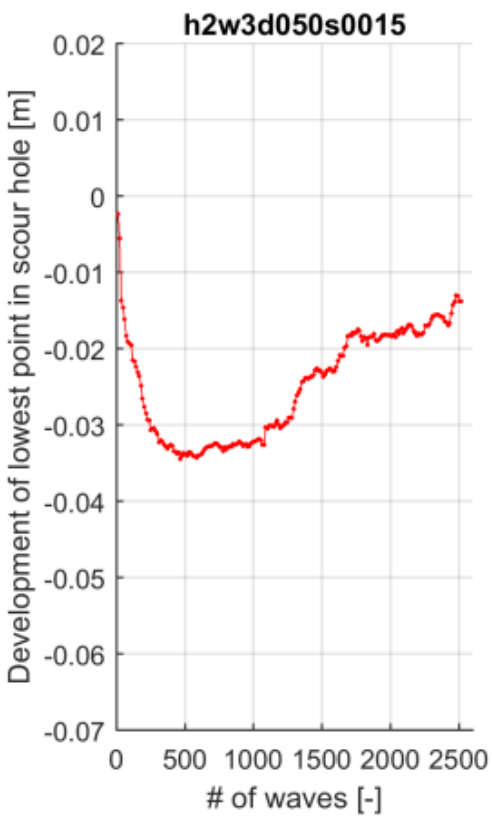
3 types of behaviour







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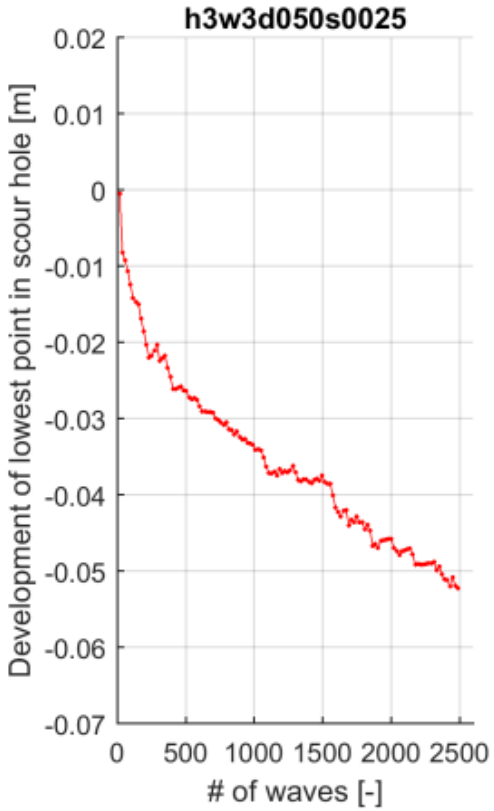
4. Results – scour hole development



Progressive scour

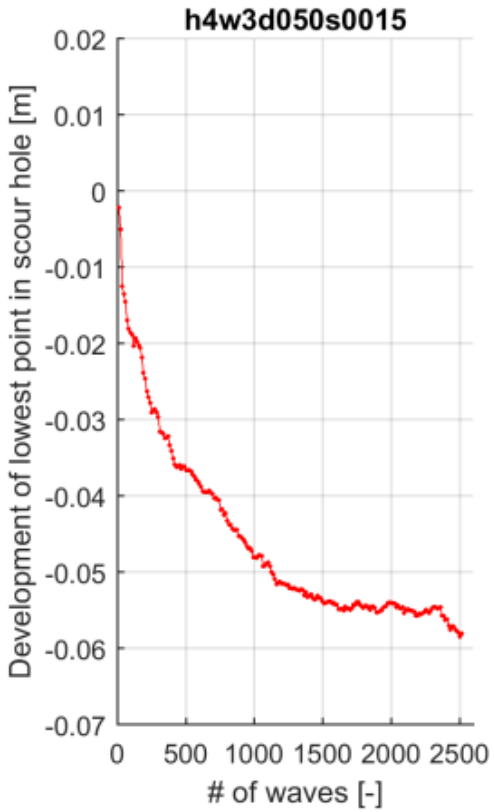
Scour hole deepens through time

No stable depth within 2500 waves

4. Results – scour hole development

Stabilizing scour

Scour hole depth stabilizes after some time



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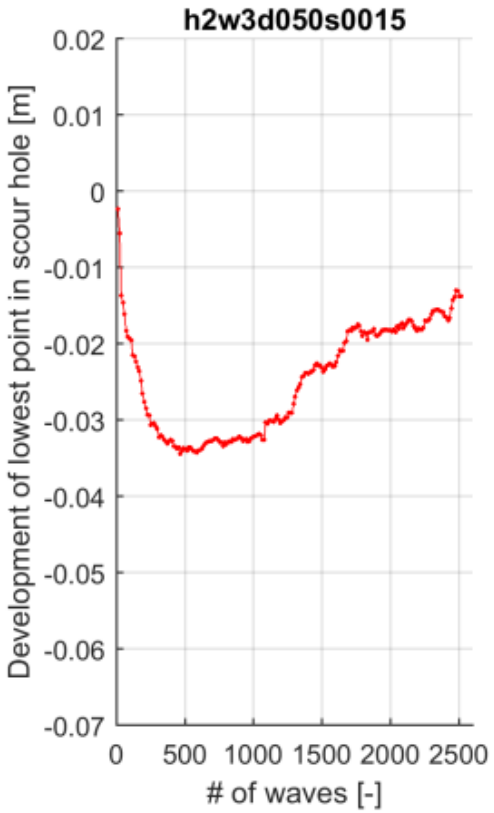
Infilling of the scour hole

1. Scour hole develops
2. Reaches stable depth
3. Hole starts to fill in

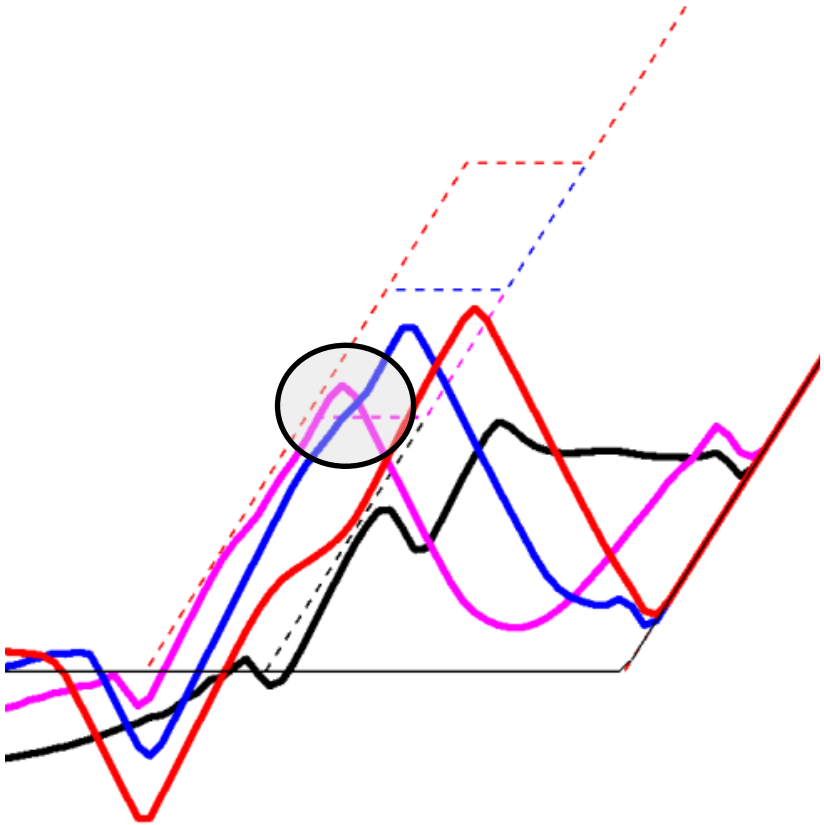
Source of sand for infilling is the sand that accumulates in the toe structure.

! observed behaviour depends on durations



5. Discussion

- Infilling of toe structure/filter in all cases
  - contrary to expectations
  - amount of sedimentation sometimes very large
  - initially developed for open filters



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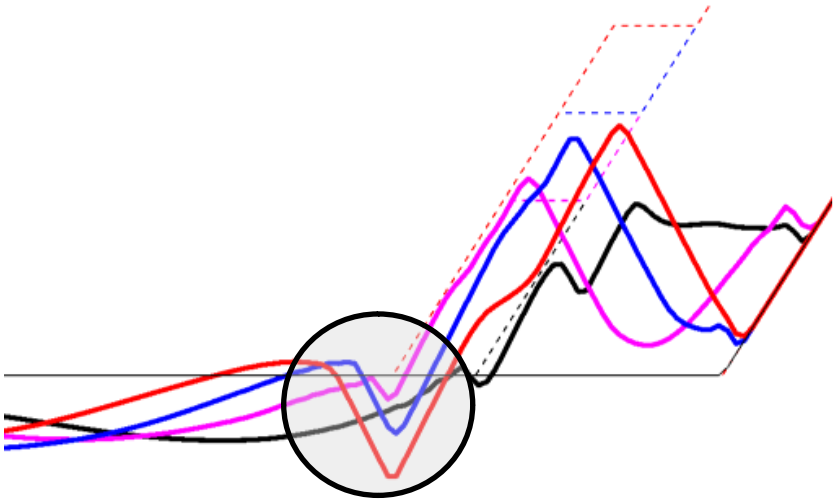
  - scour only very locally, exactly at interface
  - offshore slope expected to be gentler (currently angle of repose)



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  - scour only very locally, exactly at interface
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- Lack of validation data underneath toe
  - Sumer & Fredsøe (2000) lacks toe structure and only has data in front of structure

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Conclusions

- OpenFOAM model was extended
  - exchange of sediment in/out porous structures
  - supports multiple different porous layers

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- Application to toe structures
  - more morphological change for smaller water depth/wave steepness
  - larger scour depth for higher and wider toe structure
  - ... but infilling of scour hole determines scour depth after 2500 waves

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Conclusions

- OpenFOAM model was extended
  - exchange of sediment in/out porous structures
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- Application to toe structures
  - more morphological change for smaller water depth/wave steepness
  - larger scour depth for higher and wider toe structure
  - ... but infilling of scour hole determines scour depth after 2500 waves

- Erosion/sedimentation patterns contrary to expectation
  - infilling of toe structure in all cases
  - scour hole at interface very narrow

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Recommendations

- Generate validation data: physical model experiments
  - measure the bed level change underneath the (toe) structure
  - various toe structure layouts
  - stones should be stable

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Recommendations

- Generate validation data: physical model experiments
  - measure the bed level change underneath the (toe) structure
  - various toe structure layouts
  - stones should be stable

- Re-evaluate use of bed-load type formulation
  - suitable for open filters
  - possibly not for toe structures

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SCOUR AT THE TOE OF ROCK ARMOURED STRUCTURES

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