Lecture III

4. Relevant Processes for the Hydraulic Stability of Geotextile Sand Containers

4.1 Position of the Problem and Necessity to Improve Process Understanding

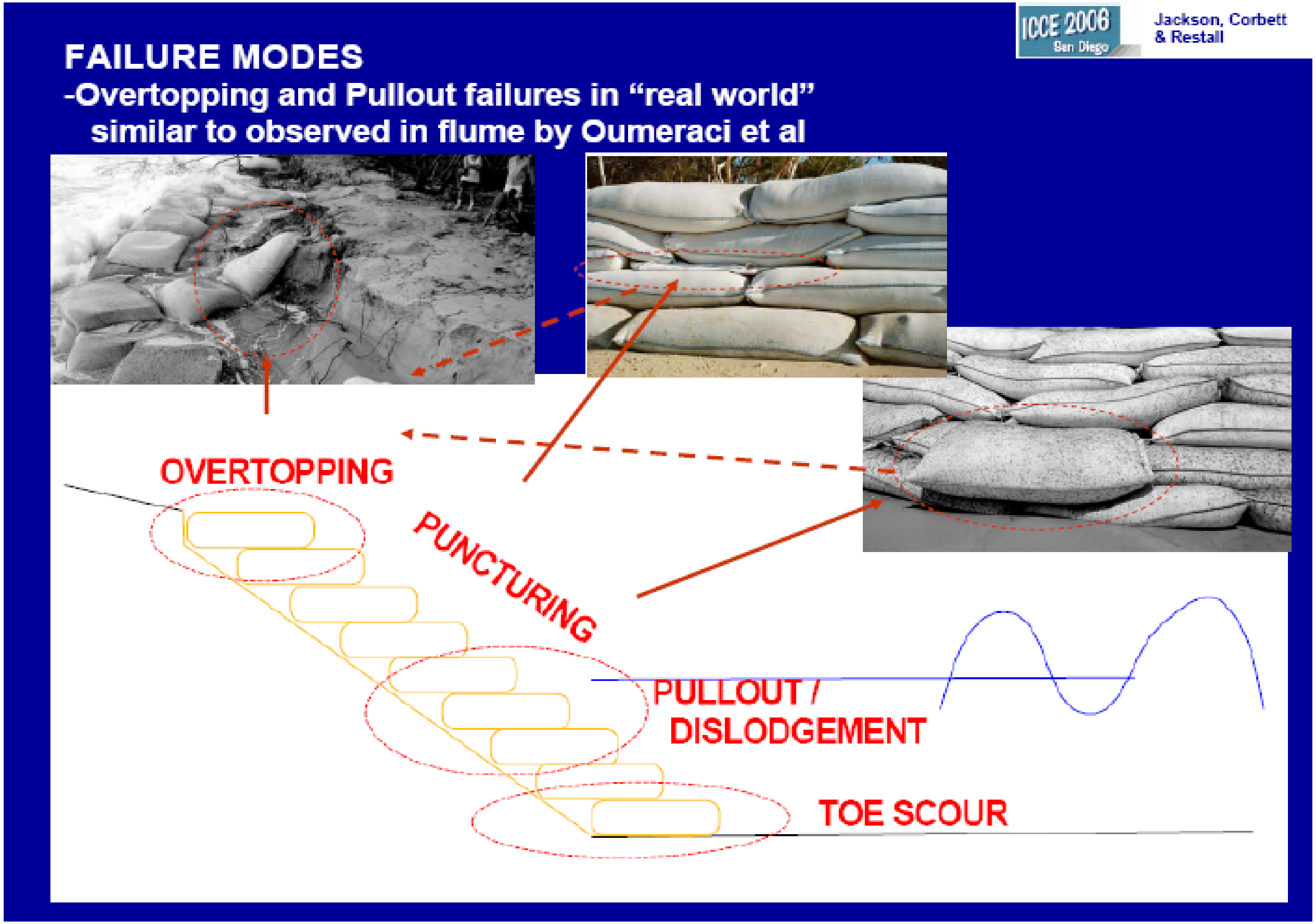
Observed Processes of Hydraulic Stability Loss

- „Pull out failure“ of Slope Containers and Sliding/Overturning of Crest Containers are strongly affected by deformations of GSCs
- Deformations of GSCs depend on several processes and interactions

- Simple HUDSON-like Formulae cannot predict reliably GSC-Stability

- Illustration by video of laboratory tests (next slide)
- Confirmation by field-observations (after video)

Video from large-scale tests (150 litre GSCs)



(Jackson et al, 2006)

Which Processes need to be better understood?

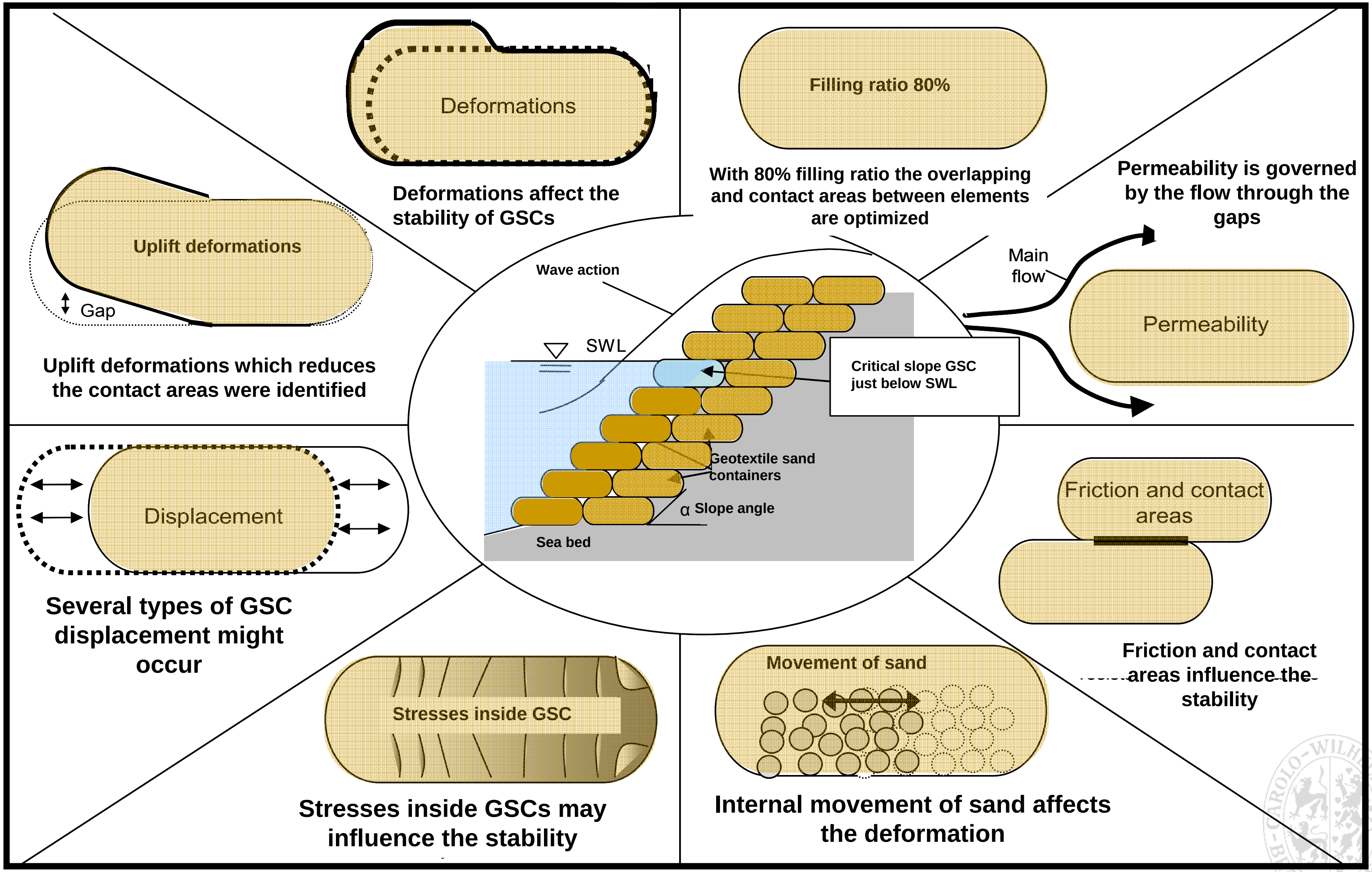
- Why slope GSCs just below SWL are most critical?
- Why are crest GSCs much more critical than slope GSCs?
- How and when GSC-deformations do occur?
- How deformations do affect hydraulic stability?

Need to understand processes leading to failure for two major reasons:

1. Possibility to avoid failure through engineering judgment - even without applying stability formulae
2. Develop more process-based stability formulae

4.2 Most Relevant Process Affecting Hydraulic Stability of Geotextile Sand Containers (GSCs)

Overview of Processes Affecting Hydraulic Stability of GSCs



4.2.1 Effect of Permeability on Hydraulic Stability of GSC-Structure

Permeability Coefficients of GSC-Structure for Different Mode of Placement (Tests in LWI-Flume)

Model Structure	Description	Darcy's Permeability Coefficient *k* (m/s)
	Structure made of geotextile sand containers **placed interlaid** blocking the gaps of the previous layer	**1.244×10^{-2}**
	Structure made of geotextile sand containers **placed longitudinally** to the flow	**2.274×10^{-2}**
	Structure made of geotextile sand containers **placed randomly**	**2.412×10^{-2}**
	Structure made of **gravel** (D_{50} = 2.3 cm, D_{max}=2.9cm, D_{85}/D_{15}=1.4).	**3.881×10^{-1}**

Remark: Permeability of gravel is normally higher than 10^{-2}m/s and permeability of sand is between 1×10^{-3} and 3×10^{-3}m/s.

Effect of Permeability and Mode of Placement on the Stability of GSC-Structure (Tests in LWI-Wave Flume)

Mode of Placement of GSCs	Wave Height H [m]	Wave Period T [sec]	Water Depth d [m]	Hydraulic Stability	GSCs Displaced after Wave Action
Longitudinal	H = 0.08	T = 2	d =0.50	Stable	0
	H = 0.12	T = 2	d =0.50	Stable	0
	H = 0.16	T = 2	d =0.50	Stable	0
	H = 0.20	T = 2	d =0.50	Stable	0
	H = 0.24	T = 2	d =0.50	UNSTABLE	9
Interlaid	H = 0.08	T = 2	d =0.50	Stable	0
	H = 0.12	T = 2	d =0.50	Stable	0
	H = 0.16	T = 2	d =0.50	UNSTABLE	38
Random	H = 0.08	T = 2	d =0.50	Stable	0
	H = 0.12	T = 2	d =0.50	Stable	0
	H = 0.16	T = 2	d =0.50	UNSTABLE	23

- Mode of placement of GSC affects permeability of GSC-Structure.
- Randomly and longitudinally placed GSCs have approximately the same permeability ($k=2.4 \cdot 10^{-2}$ m/s and $k=2.3 \cdot 10^{-2}$ m/s, respectively).
- Permeability does affect stability of GSCs, but correlation still not clear.
- Computations using RANS-Model confirmed the assumption that the permeability is governed by gaps between GSCs (Flow through sand fill is negligible!).

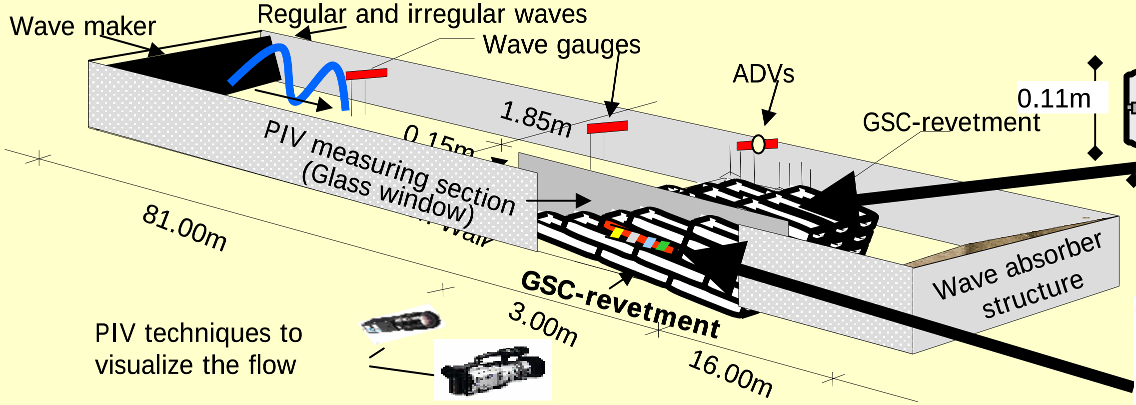
→ For more details see Recio and Oumeraci (2006) and Recio (2007).

4.2.2 Processes and Wave-Induced Forces During Up-Rush and Down-Rush - Effect on Hydraulic Stability

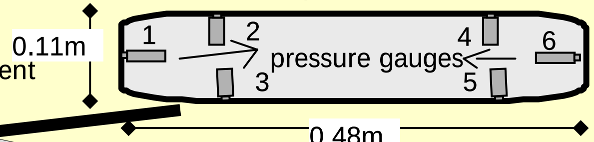
4.2.2.1 Experimental Set-Up and Observation Techniques to Study the Processes

Experimental Set-up in the LWI-Wave-Flume

(a) General View



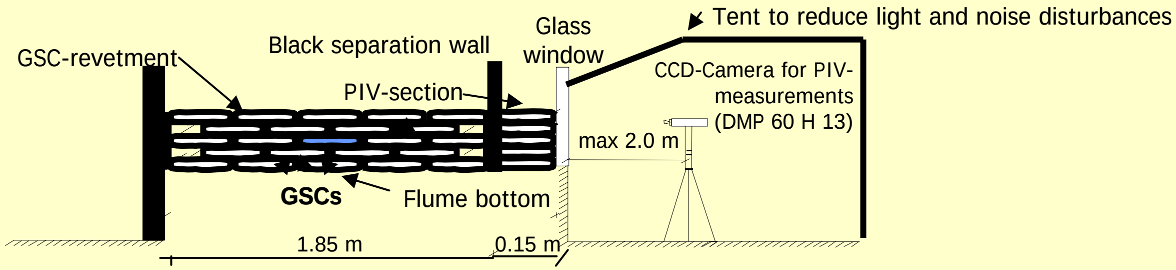
Instrumented container with pressure gauges inside to record wave-induced pressures



Transparent permeable container to observe the internal movement of coloured sand

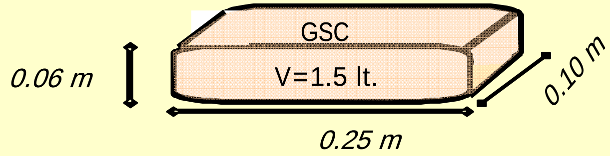
(b) Frontal View

Wave Conditions:
H= 0.08 – 0.20 m
T= 1.5 – 4s
d= 0.52, 0.61, 0.70m



(c) Cross Section: GSC-structure in PIV-measuring section

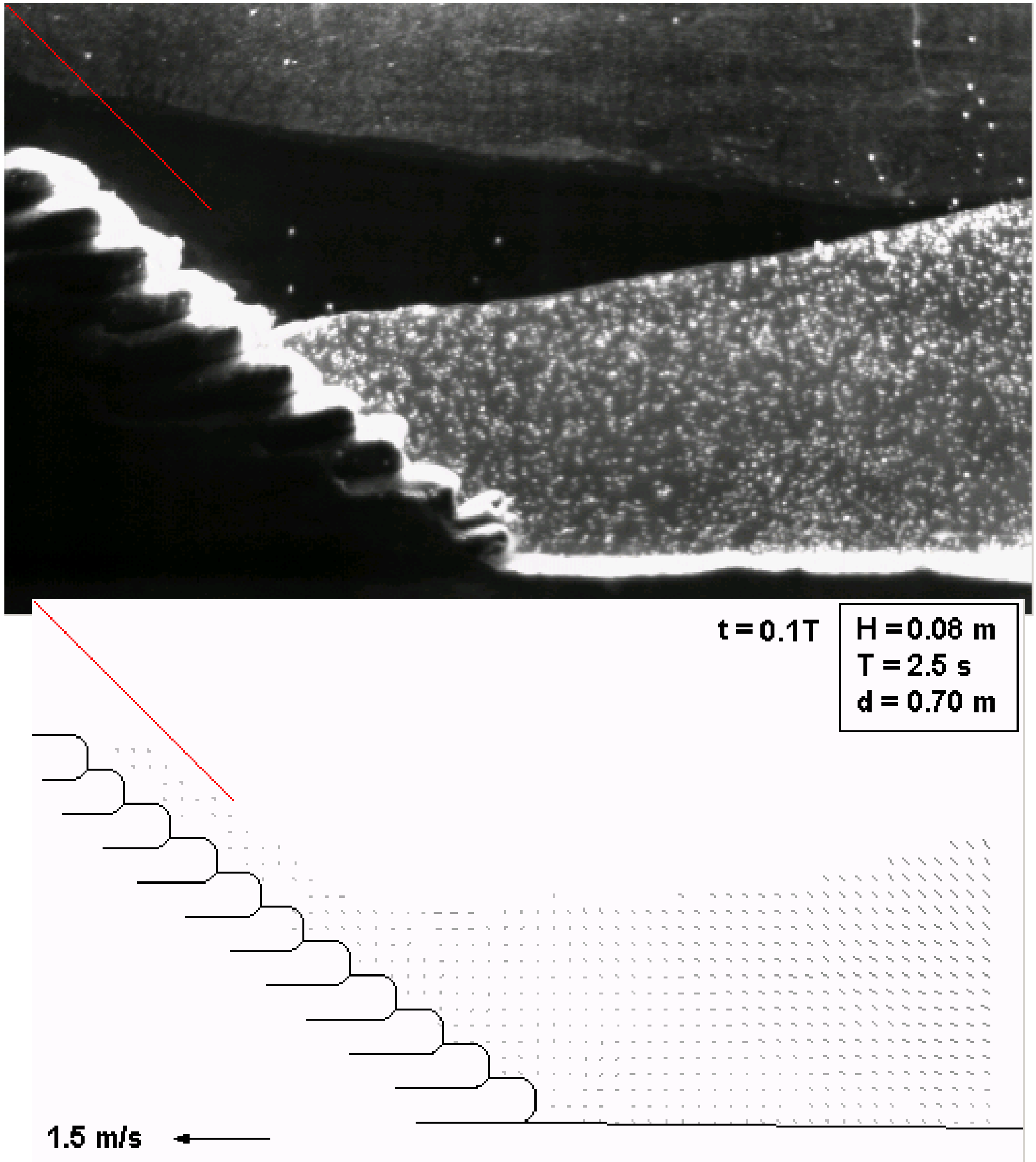
Dimensions of the containers used to built the GSC-revetment in the PIV-measuring section



GSC in "PIV-section"

Permeable Transparent GSC Used to Investigate the Internal Movement of Sand

Wave-Induced Flow on a GSC-revetment

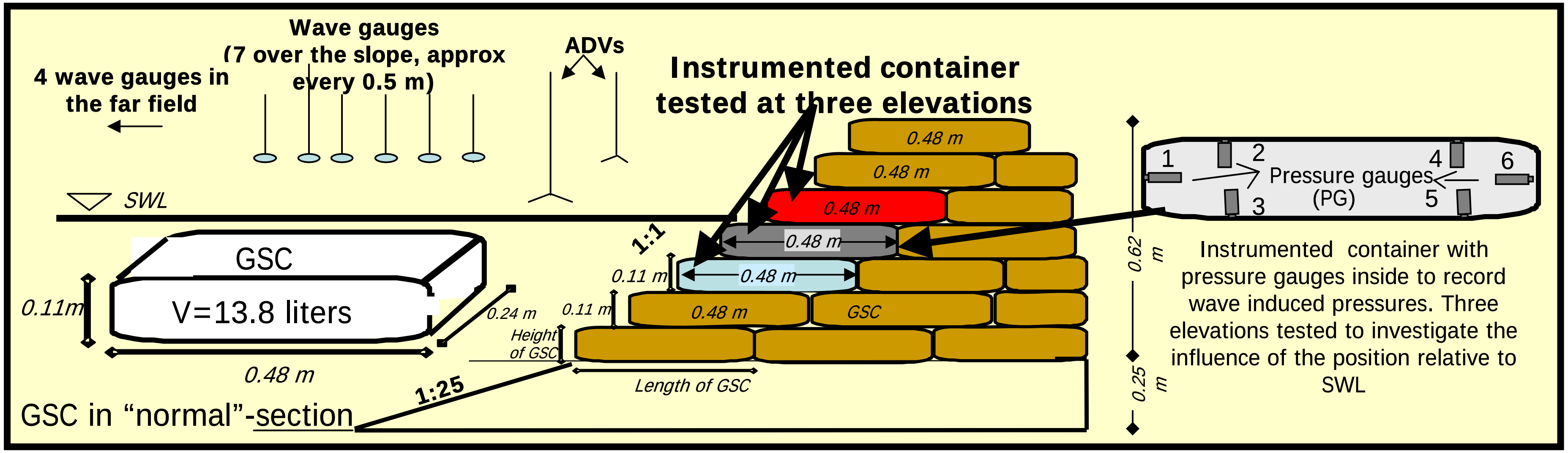


PIV-videos

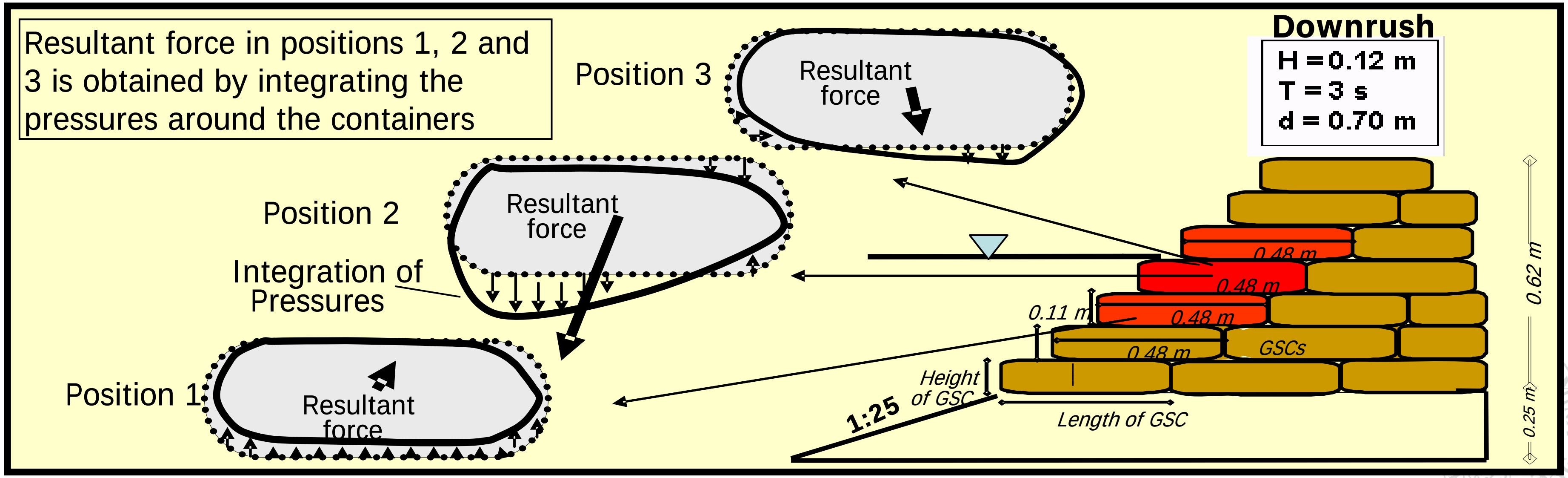
Wave-Induced Flow on a GSC-revetment: Local Effects

Well-structured vortices characterized by fluid particles moving around a common centre. These vortices appear in the areas between containers.

Non-structured vortices occurring during up rush induced by higher waves (higher than 0.12m)

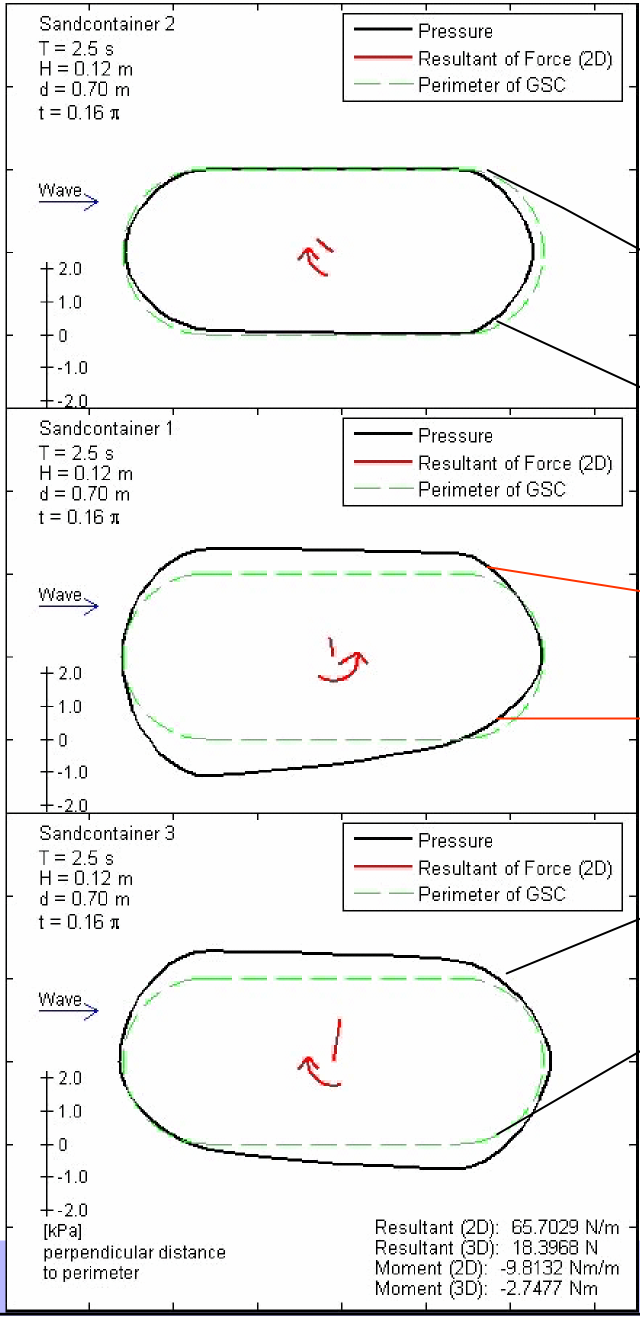


(a) GSC-Structure in the Wave-Flume (adjacent to PIV-measuring section)

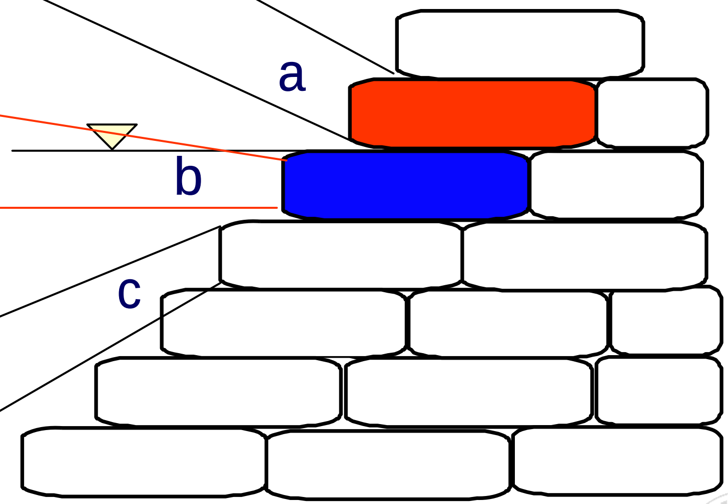


(b) Wave-Induced Loads on Instrumented Sand Container During Wave Down Rush

Wave-Induced Pressures on GSC: Animation from measured data



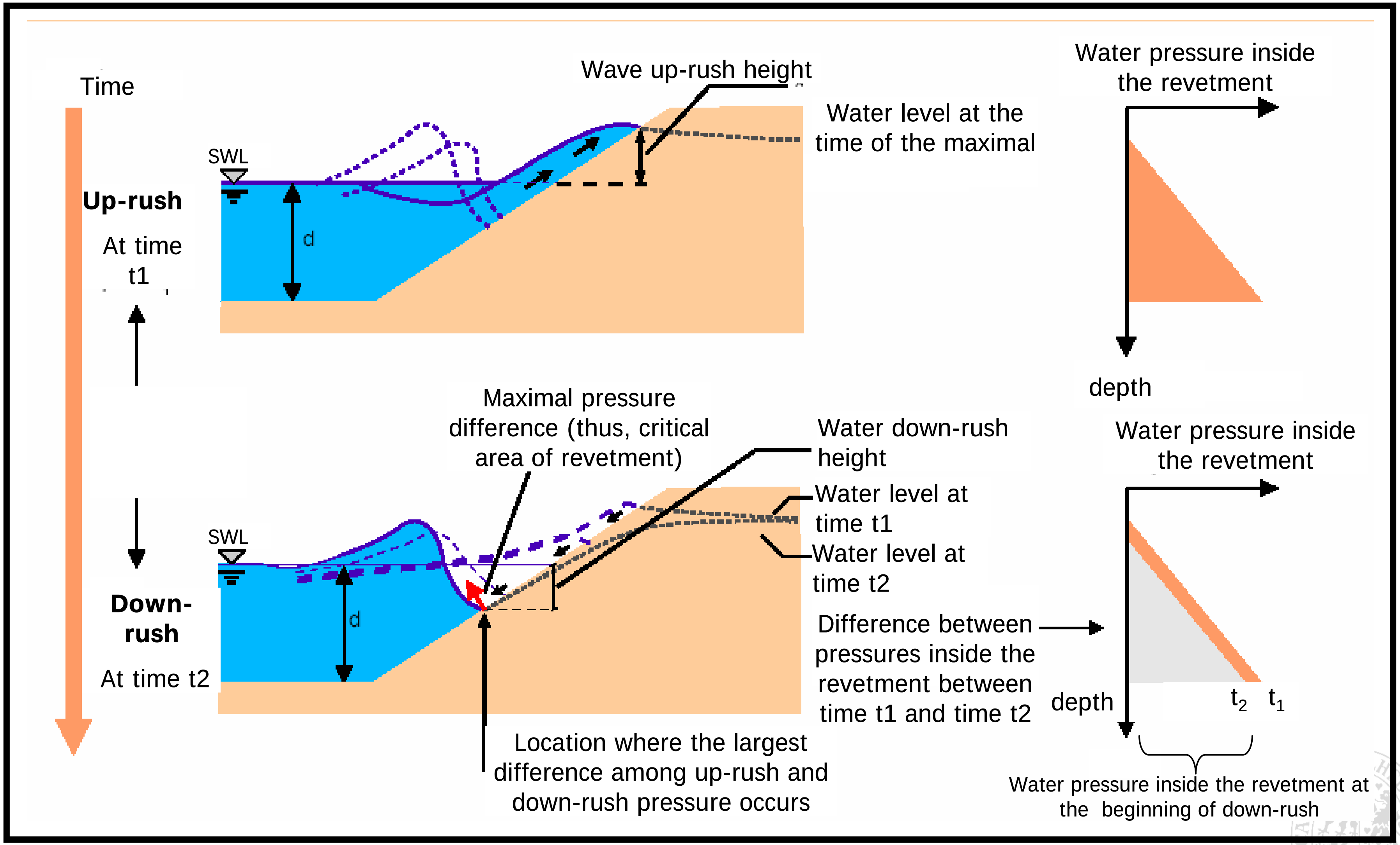
Wave Height = 0.12 m
Wave Period = 2.5 s
Wave depth = 0.70 m



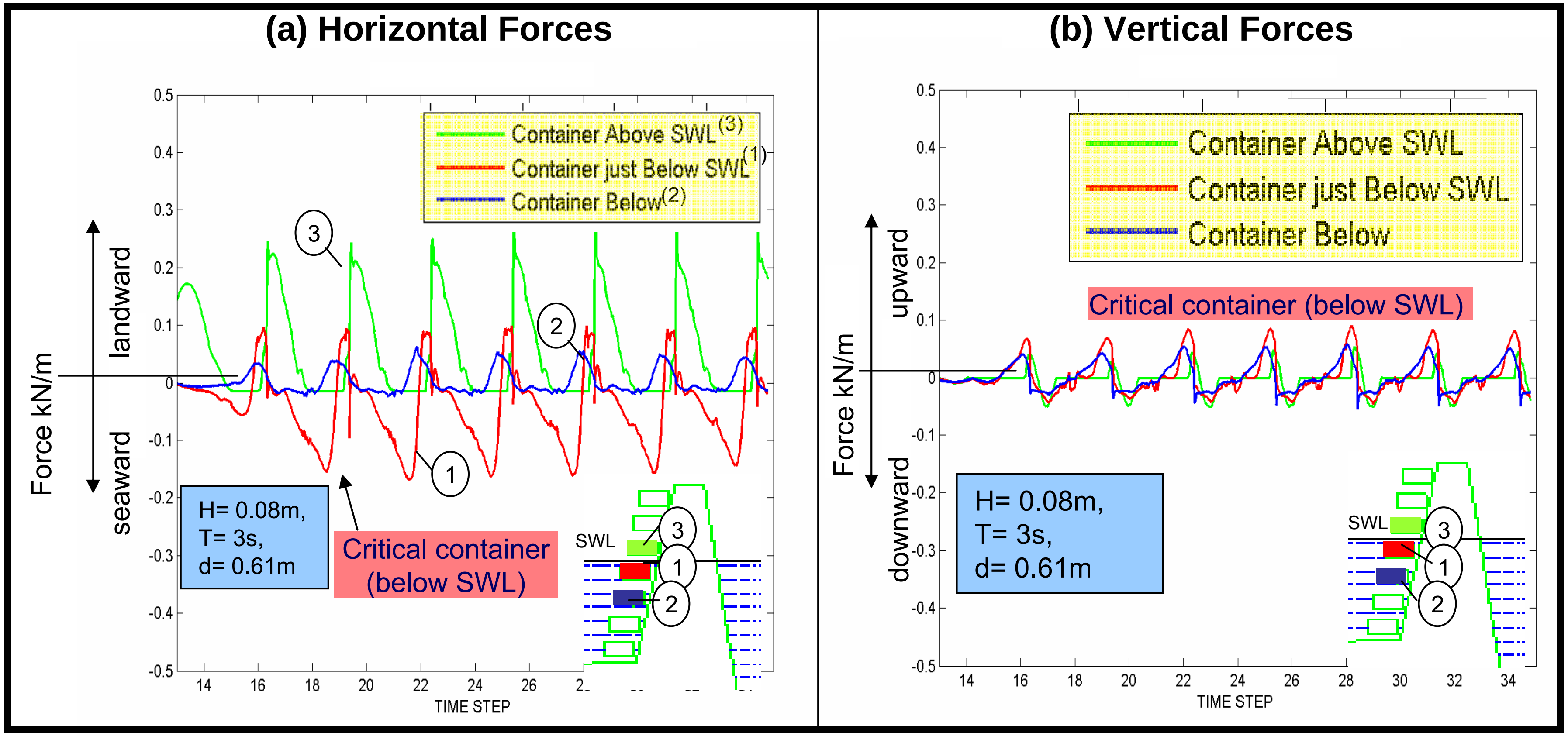
By integrating the neasured wave-induced pressures the critical stability situation and the influence of the wave parameters on the resultant force were identified

4.2.2.2 Wave-Induced Forces During Up- and Down-Rush-Critical Location of GSCs on Slope

Wave-Induced Pressure on and in GSC-Structure During Up- and Down-Rush



Wave-Induced Forces on Slope GSCs: Identification of Critical Slope Container Location

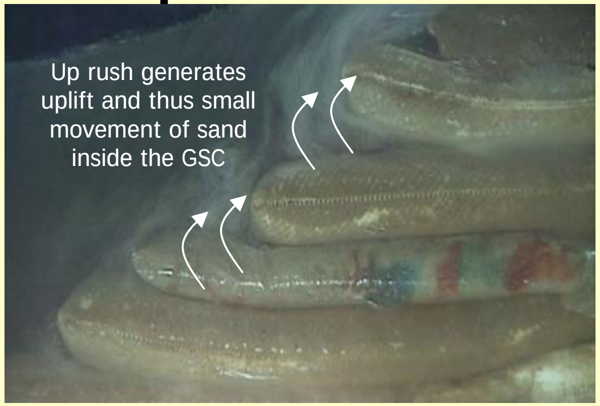


Most Critical Location of Slope GSCs: Just Below SWL!

4.2.2.3 Internal Sand Movement in GSC and Its Effect on Sliding and Overturning Stability

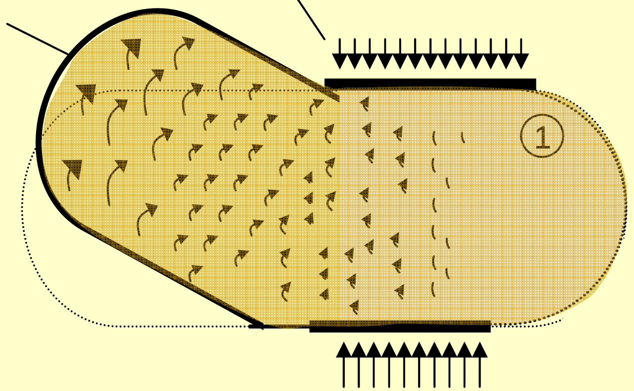
Internal Movement of Sand inside the Transparent Permeable Container (1)

a) Wave Up-Rush Phase



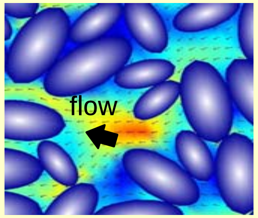
Arrows represent movement of sand-particle

External load caused by weight of neighboring GSCs

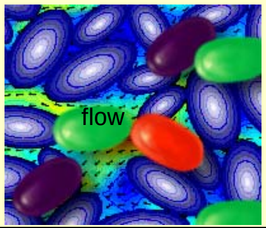


b) Wave Down-Rush Phase

Close-up of Sand Particles First Down-Rush



Second Down-Rush

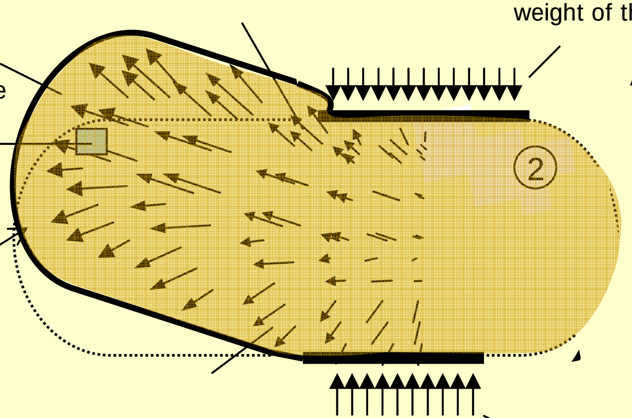


With every down-rush more particles move to the frontal part of the GSC until the sand is re-accommodated

Arrows represent movement of sand-particle

Close Up

External load caused by weight of the GSCs above



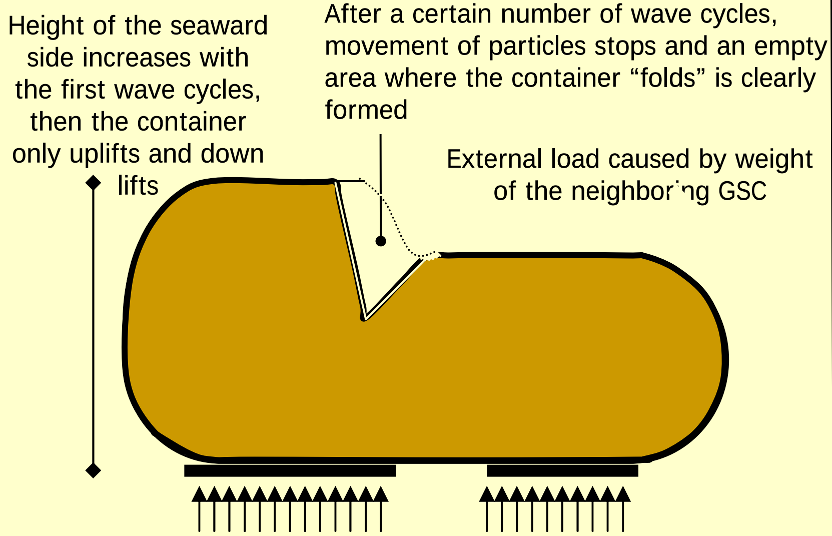
Grains accumulate in the frontal part during the first wave cycles

Loaded area by GSCs below

Affects
- Height of GSC-Structure
- Stability of GSC-Structure
  - Slope GSCs
  - Crest GSCs

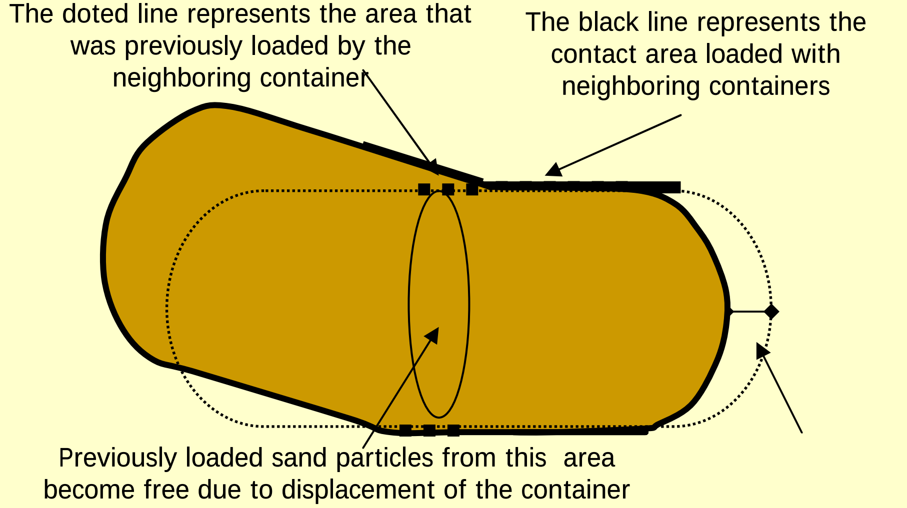
Internal Movement of Sand inside the Transparent Permeable Container (2)

(c) Sand Fill Redistribution



After some wave cycles

(d) Lateral Displacement



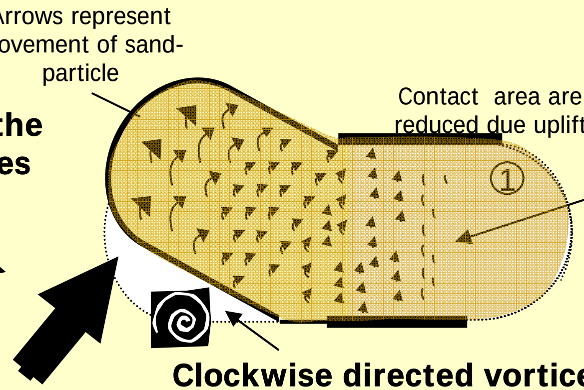
If the container is displaced, internal movement of sand will follow

Internal Sand Movement on Sliding of Slope GSC (Pull out Process)

(a) Wave Up-Rush Phase

Up-rush flow uplifts the container and reduces the contact areas

Internal movement of sand increases the uplift force



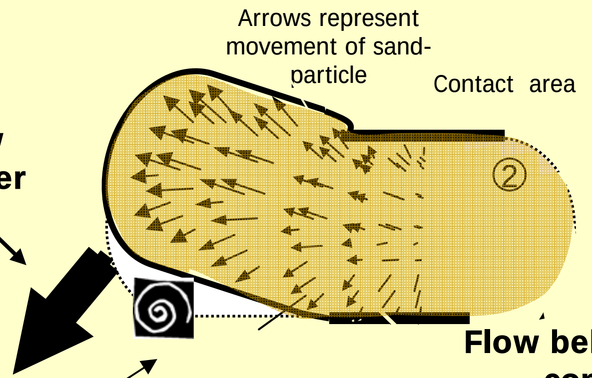
Clockwise directed vortices “trapped” between the containers may generate additional forces on the container

Sliding occurs when the container returns from its uplifted position. At this time, contact areas and resisting force are reduced.

(b) Wave Down-Rush Phase

Internal movement of sand induces deformation and reduce the resisting contact areas of the container, thus contributing to the seaward displacement of the container

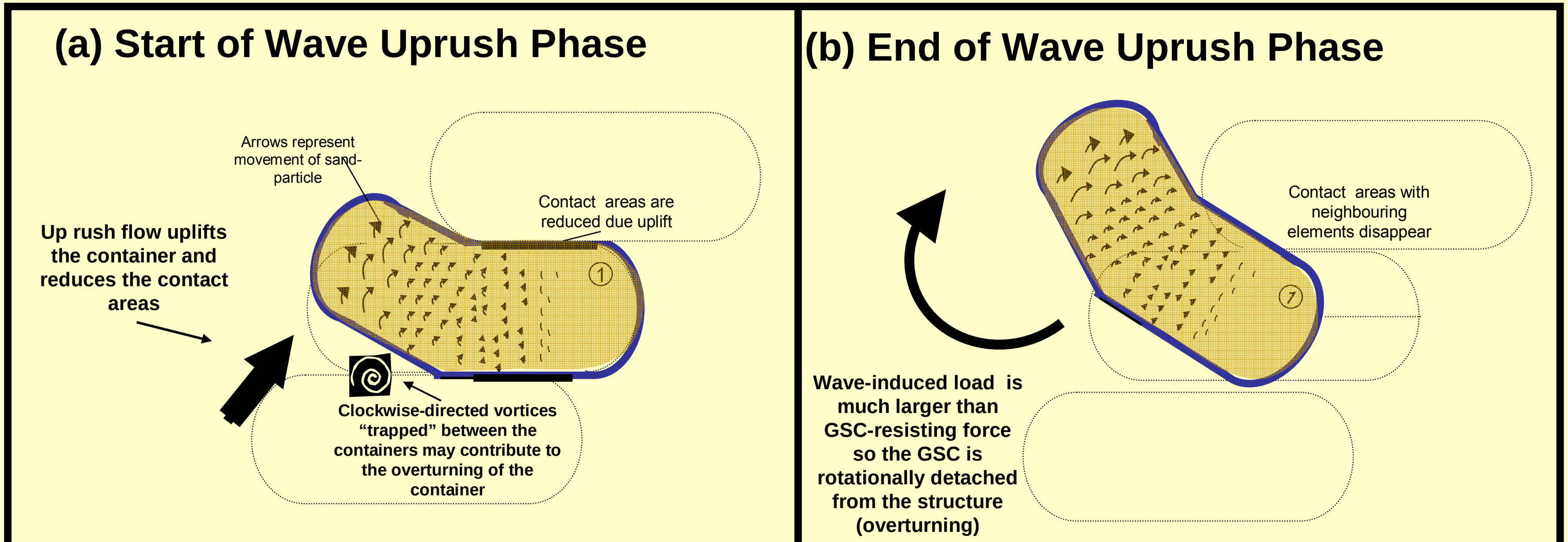
Down-rush flow pulls the container seawards



Flow behind and inside the container contributes to the seaward displacement

Counter-clockwise directed vortices “trapped” between the containers may generate additional seaward forces on the container

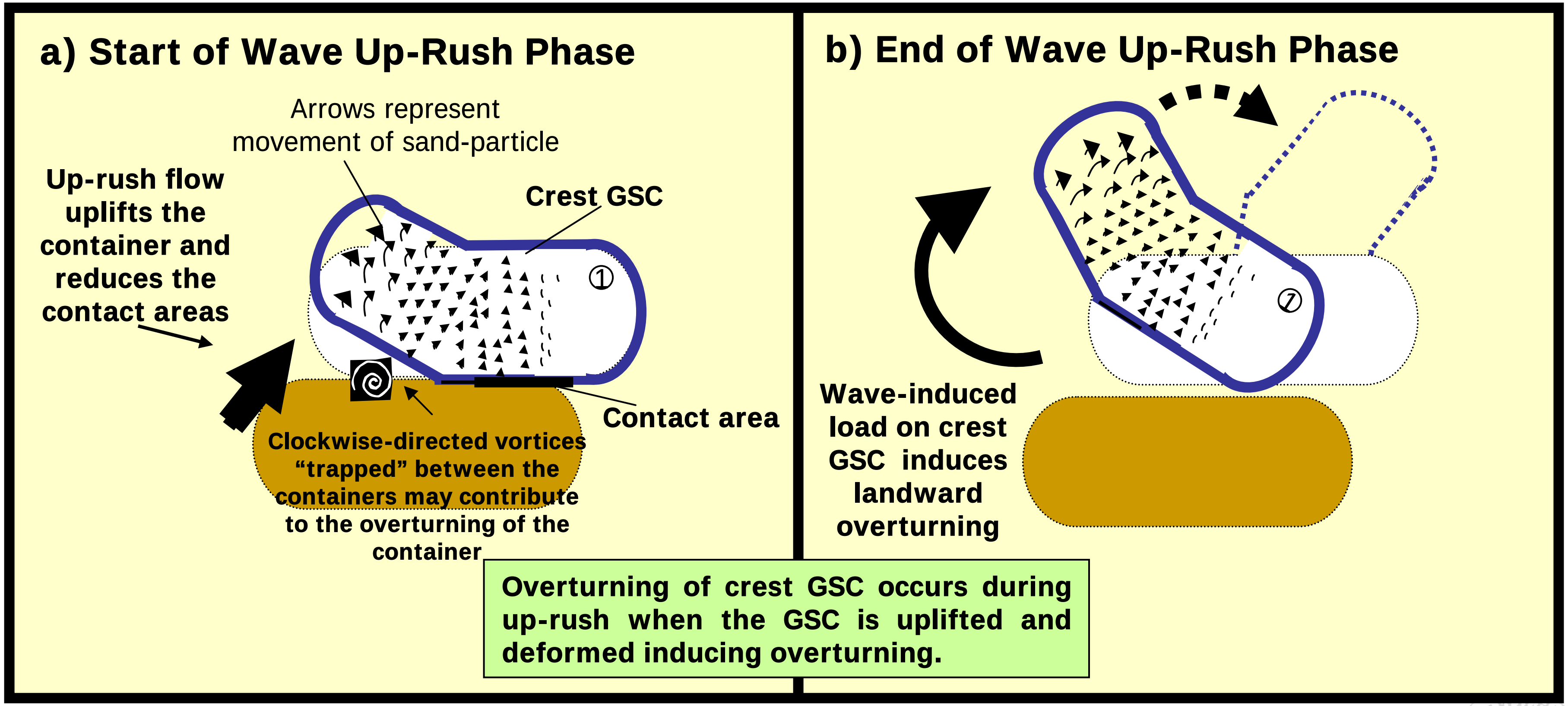
Effect of Internal sand Movement on Overturning of Slope GSC



Upward rotational displacement (overturning) due to the very large wave-induced load during uprush. GSC is "detached" from the GSC-structure

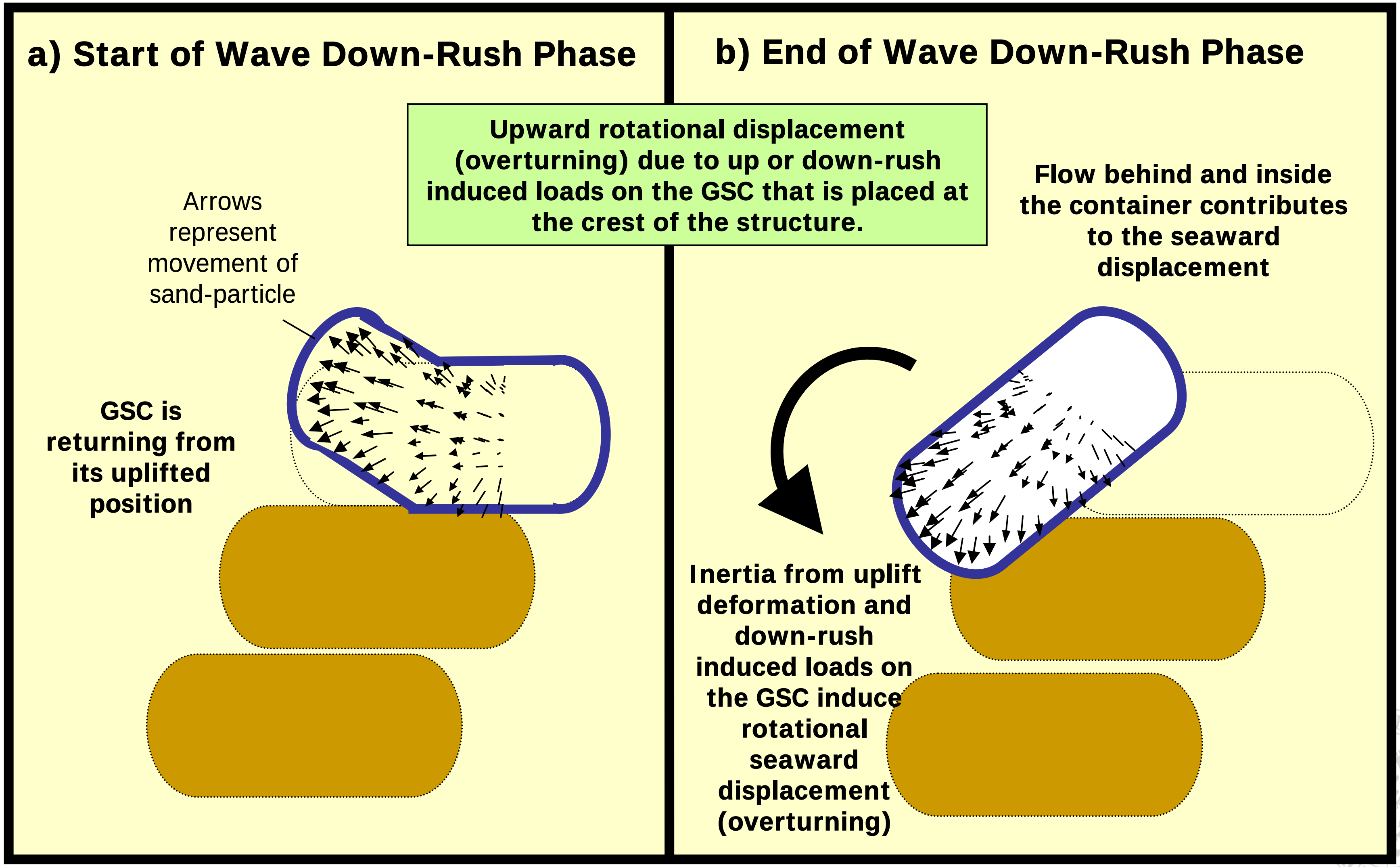
The effect of sand internal movement on both sliding and overturning of slope GSCs is the key mechanism to better understand the deformation effect on the „pull out failure“

(a) Landward Overturning of Crest GSC (Wave Up Rush)



Effect of Internal Sand Movement on Stability of Crest GSCs (2)

(b) Seaward Overturning of Crest GSC (Wave Down Rush)



4.2.2.4 Effect of Internal Sand Movement on “Settlement” of GSC-Structure

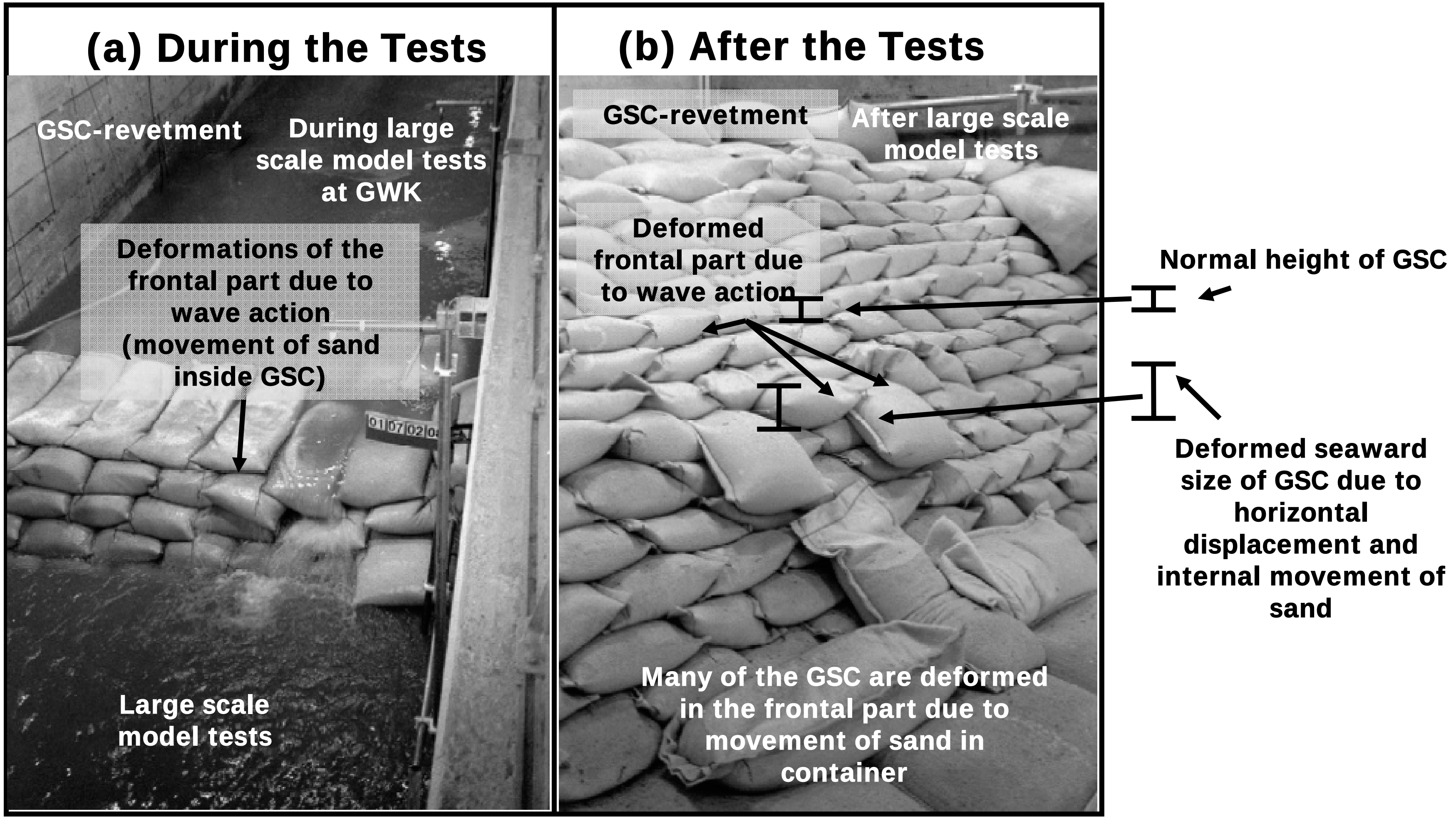
Reduction of the Height of a GSC-Structure Due to Internal Movement of Sand ("Settlement" of GSC-Structure)

(a) Dry Conditions	(b) Submerged	(c) After Wave Action

Conclusion: Initial height of the GSC-revetment is reduced approx **4 % due to wet conditions** and **6 % due to wave** action, leading to a **total reduction of the height of the GSC-structure of about 10 %** as compared with dry conditions

4.2.2.5 Effect of GSC-Deformation on Sliding and Overturning Stability

Deformations and Displacements Observed during and after the Model Tests in the Large wave Flume

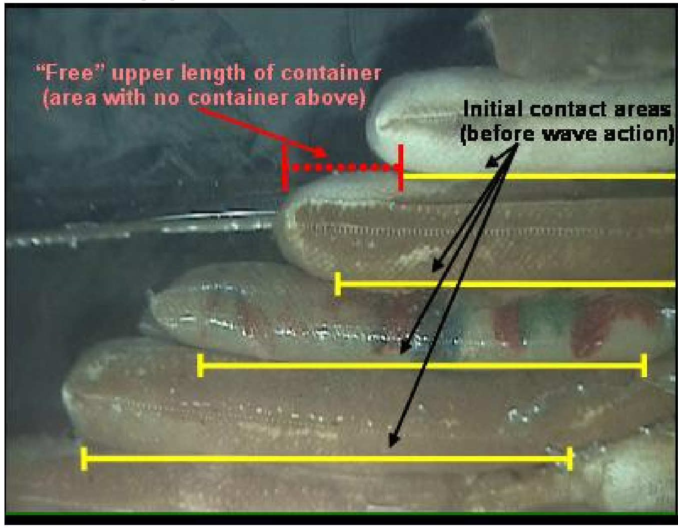


How do the deformations affect hydraulic stability?

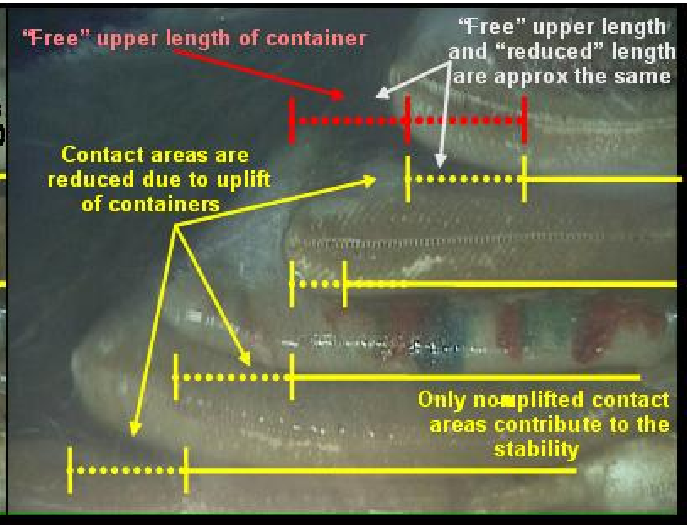
- Reduction of contact area between GSC by uplift
- Increase of drag and lift force due to increase of exposed area

Reduction of Contact Areas Between GSCs During Wave Action (Experimental Results)

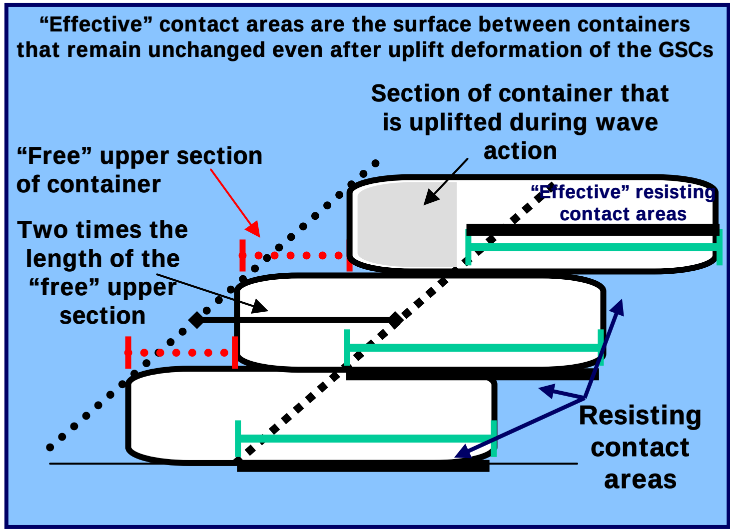
(a) Initial Contact Areas



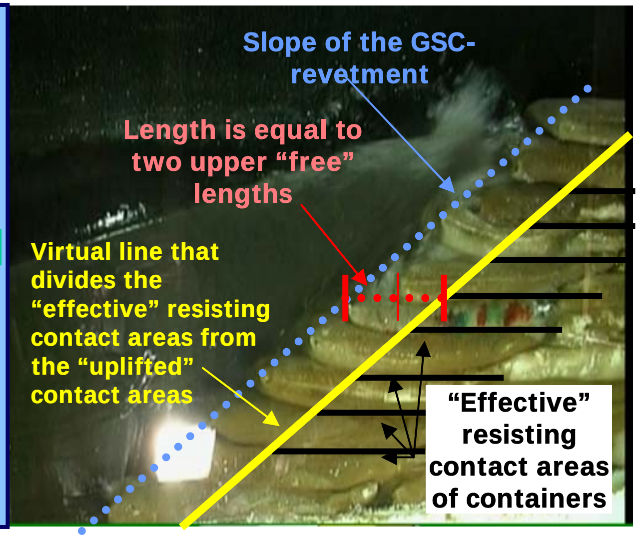
b) Reduction of Contact Areas



(c) Definition of Effective Contact Areas



(d) Distribution of Effective Contact Areas



- RANS-VOF Model } CFD
- Finite Element Model (FEM)
- Discrete Element Model (DEM)

} CSD

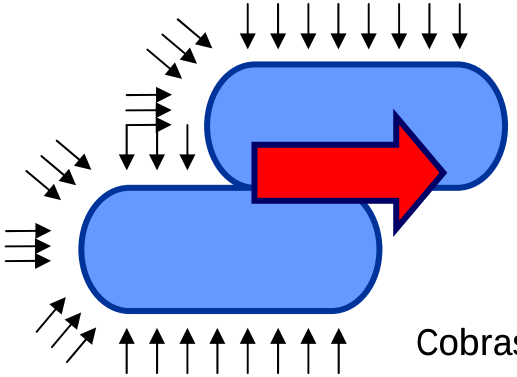
RANS-VOF Model: Cobras developed by the Team of Professor Liu, Cornell University, USA

FEM-DEM: UDEC, developed by Itasca

Three models were modified and adapted to simulate the stability of GSC-Structures

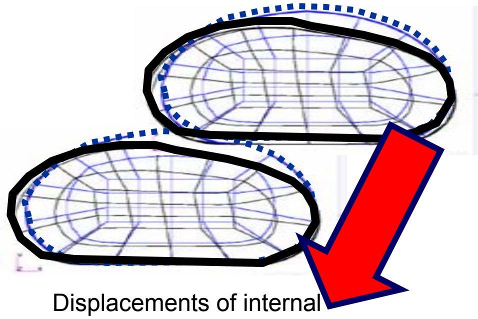
Numerical Simulations: Flow and Structural Dynamic Models

1. RANS-VOF-Model: Wave-induced pressures on the GSC.

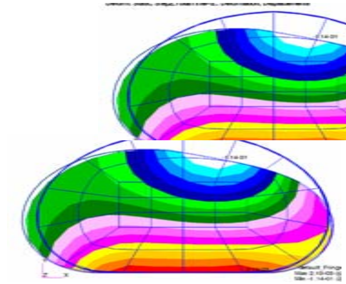


Cobras

2. FEM-Model: Calculates the stresses and deformations .



Displacements of internal nodes induced by wave induced forces



Stresses derived from the displacements of internal nodes

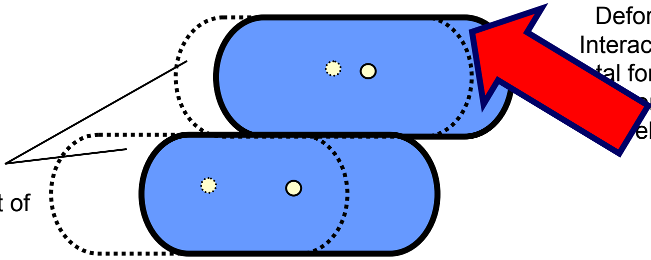
UDEC (FEM)

$T = T + \Delta t$

Next time step

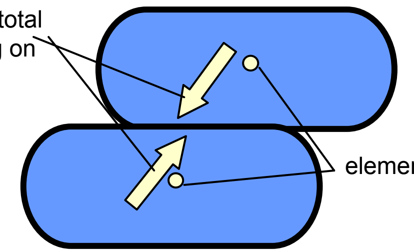
3. DEM-Model: uses the resultant forces from the FEM and calculates the displacements of GSCs

displacement of elements



Step 3
Element Motion

Deformation and Interaction between
...tal forces and total
...nts acting on
elements



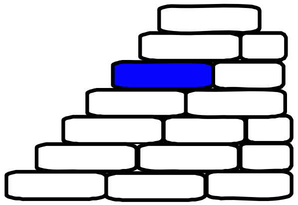
element center

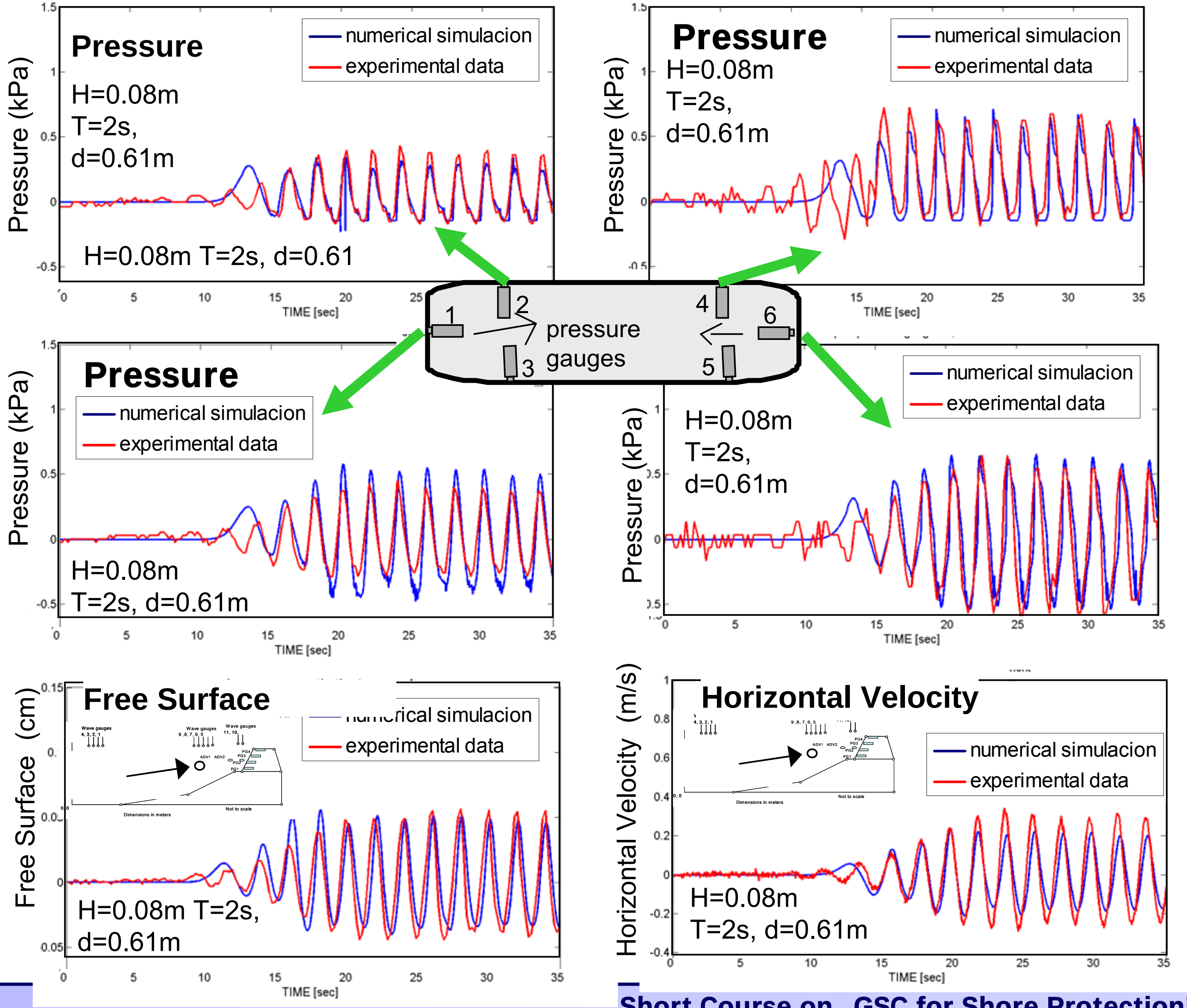
Step 2
Interaction of Forces

UDEC (DEM)

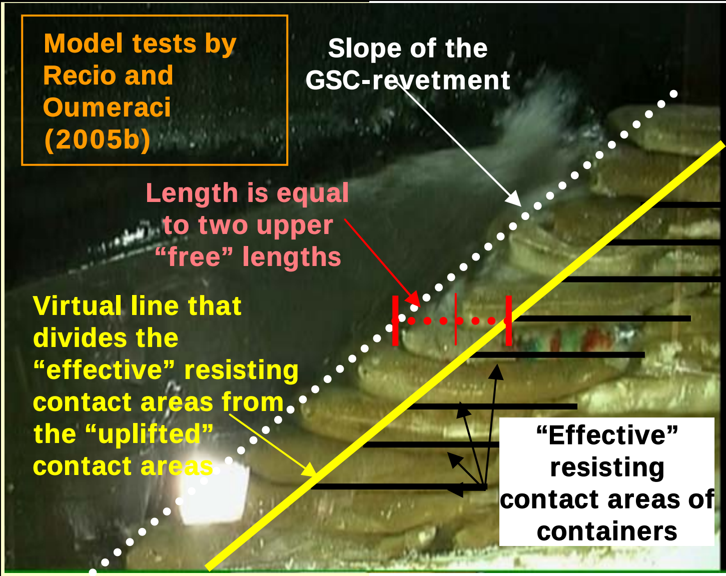
Validation of the Flow Model (RANS-VOF)

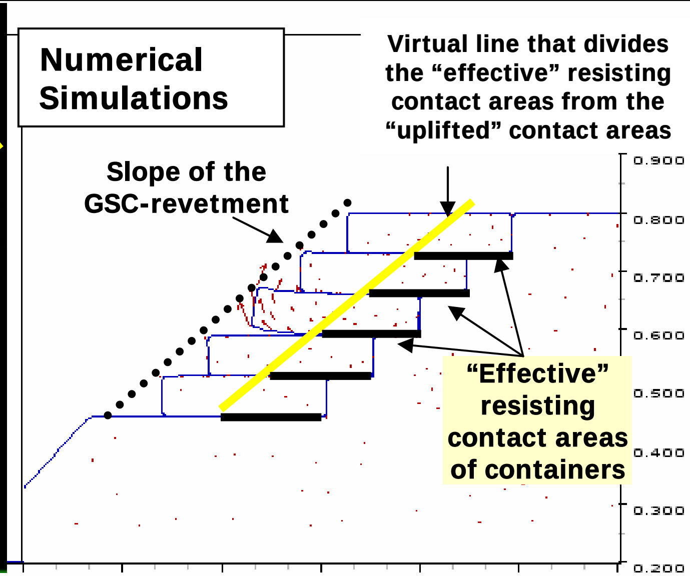
c) Comparison between Numerical and Experimental Results



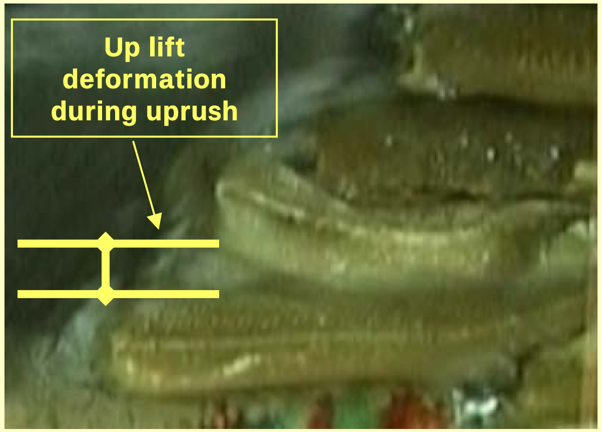


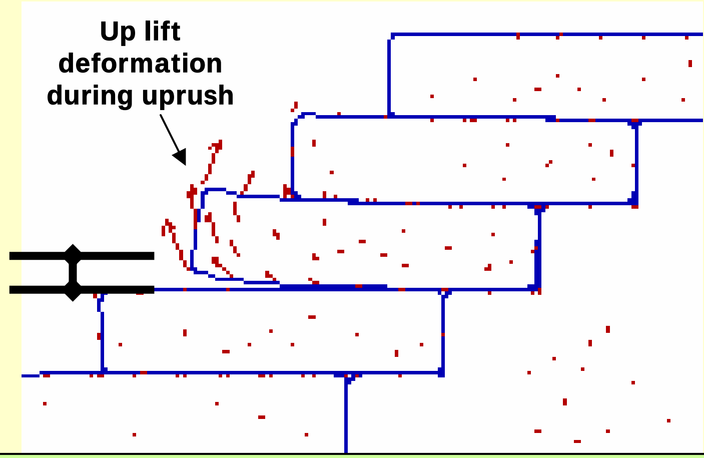
Reduction of Contact Areas Between GSCs During Wave Action (Experimental and Computational Results)



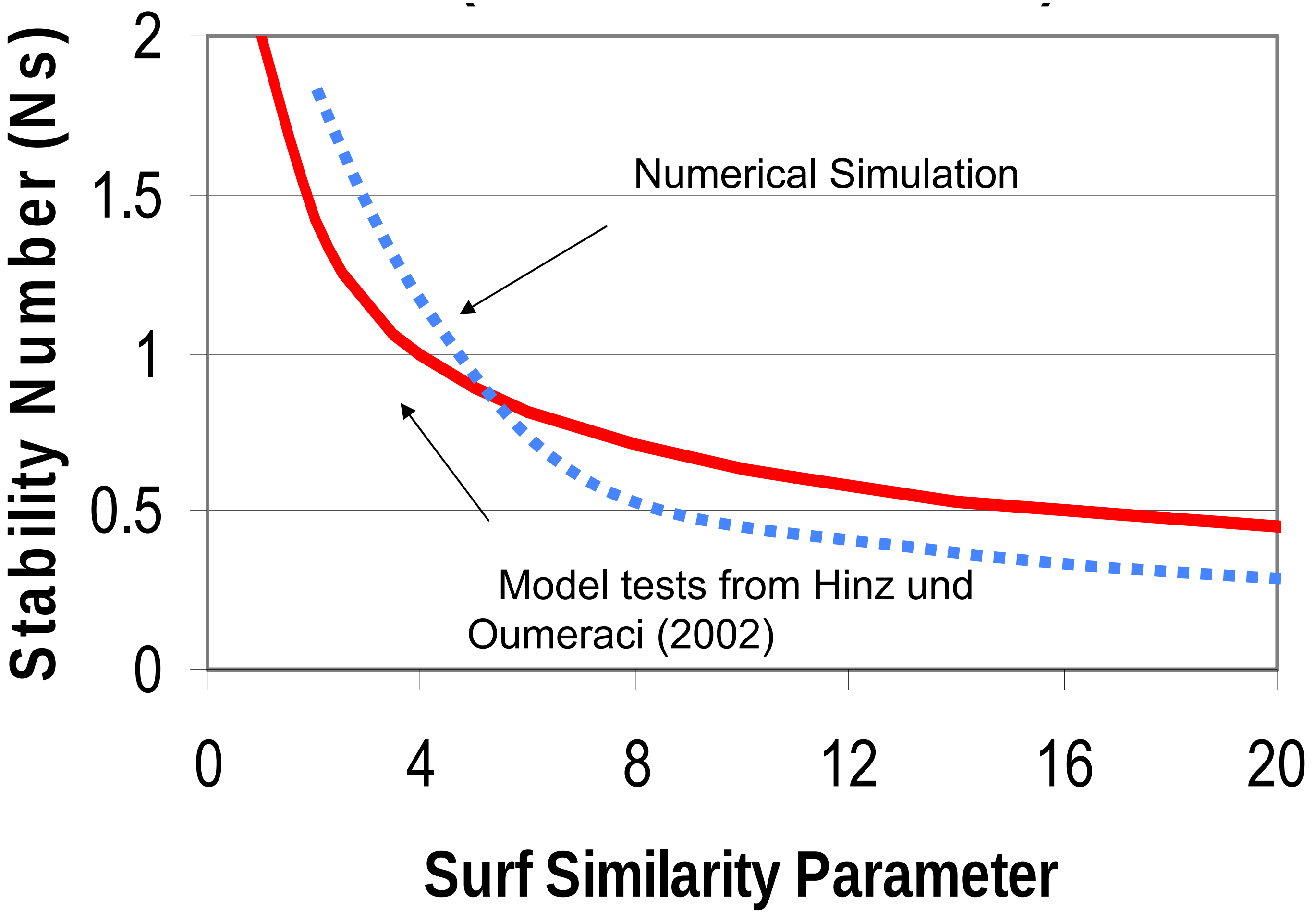


Contact areas between neighbouring GSCs after uplift deformation are slightly smaller in the numerical simulation than in the model tests (around 12 %)



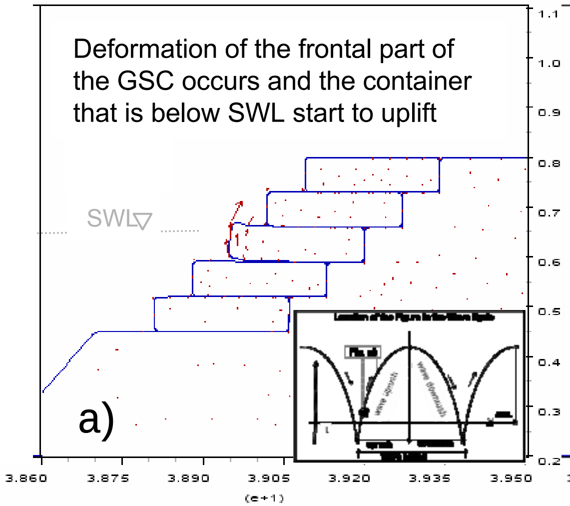


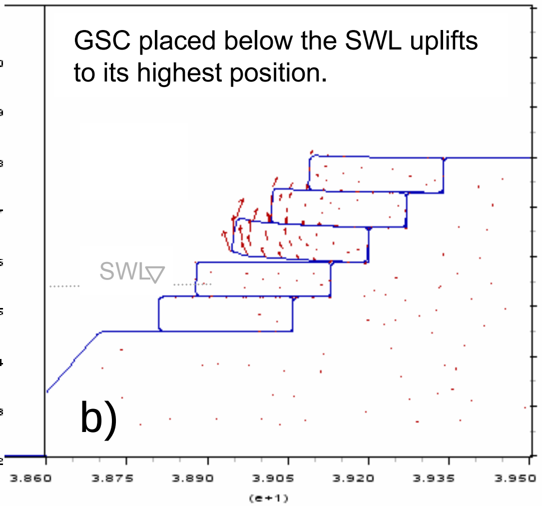
Uplift deformation during uprush are smaller in the numerical simulation than in the model tests (around 29 %)

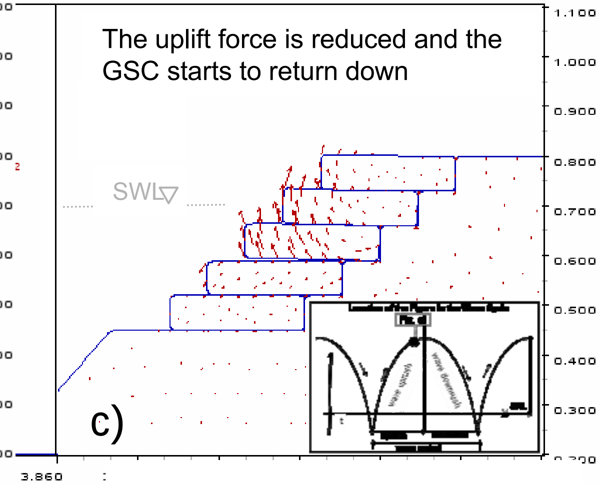


Relatively good agreement between experimental results and numerical simulations

Wave Uprush



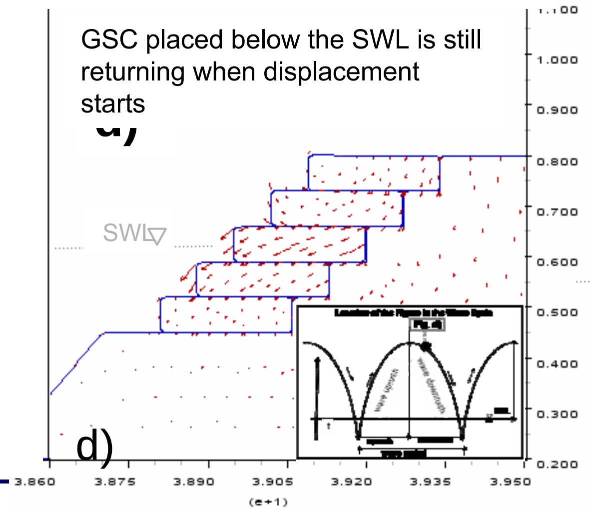


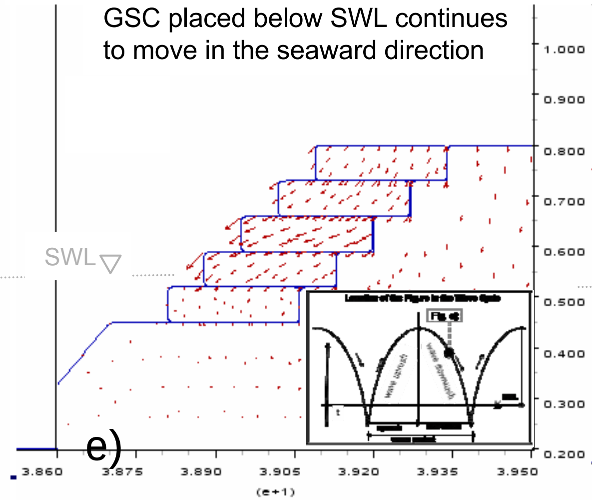


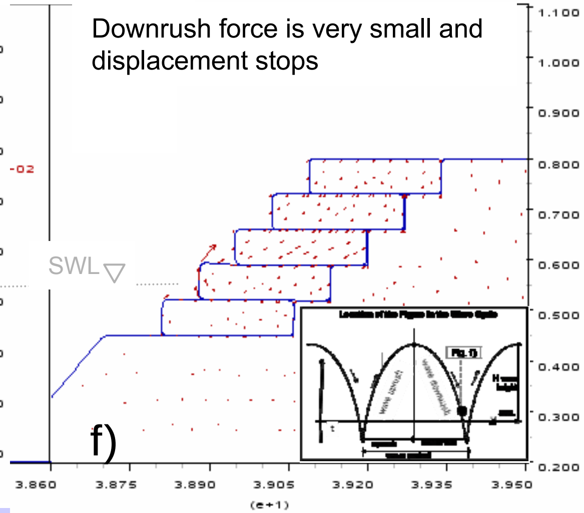
[H20-T2-d61.avi]

[juan2rapidisimo.mov]

Wave Downrush

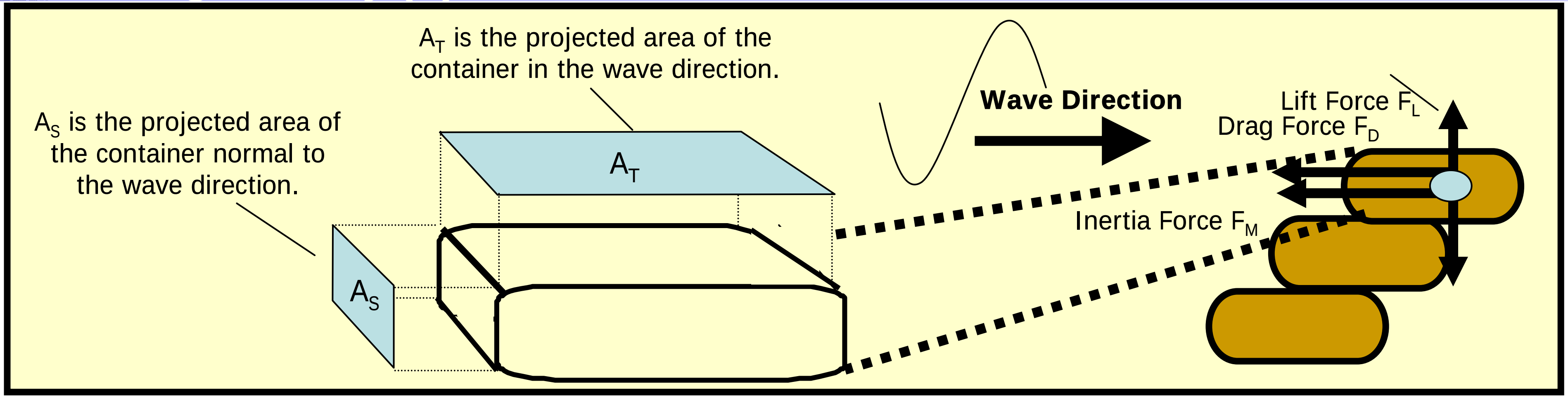




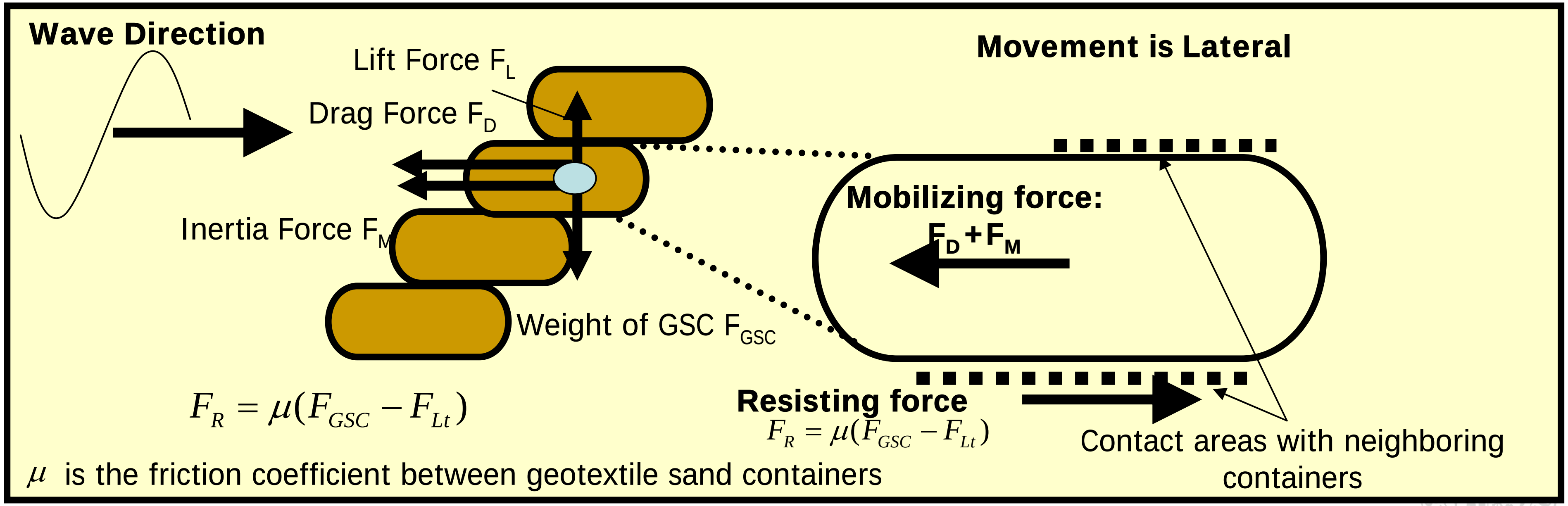



H20-T2-d61
Januar 2007

Increase of Exposed Areas for Drag and Uplift Force-Effect on Sliding Stability (1)

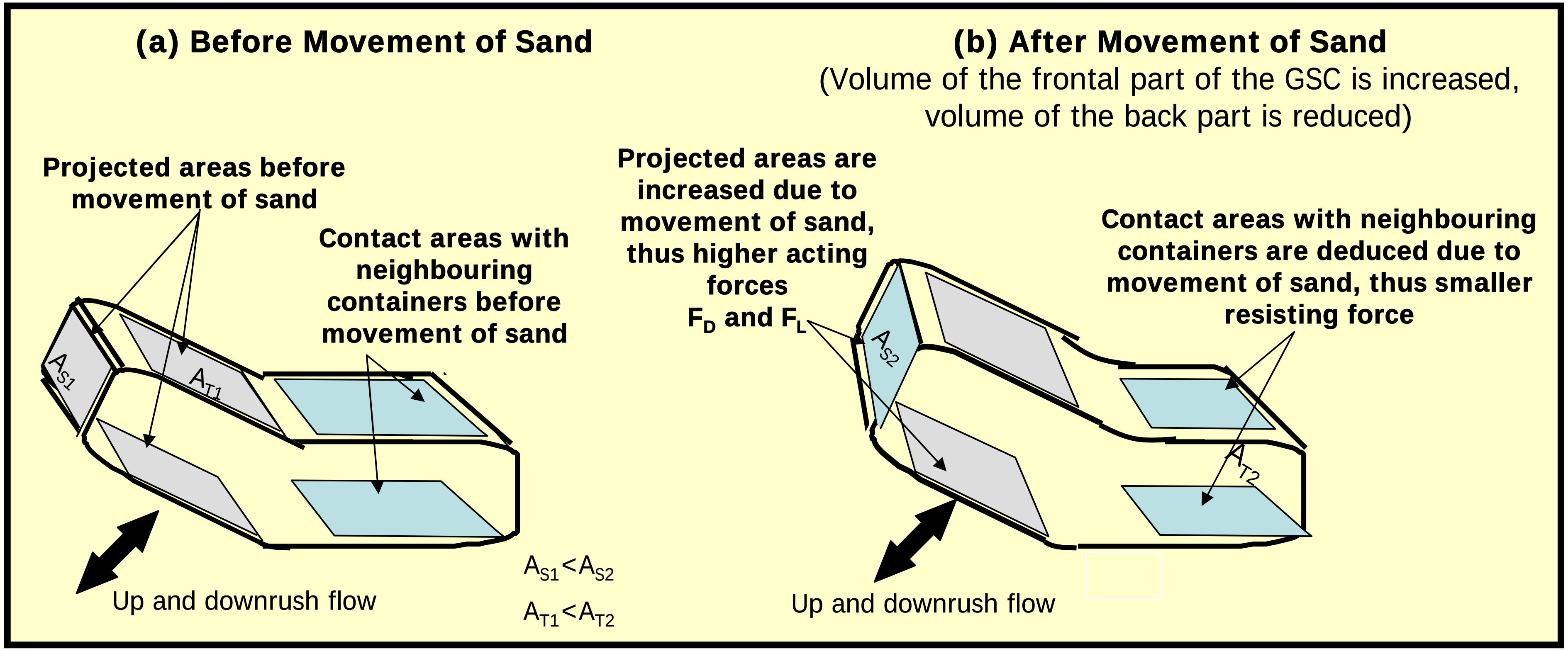


(a) Projected Areas A_S and A_T of a Sand Container without Deformation



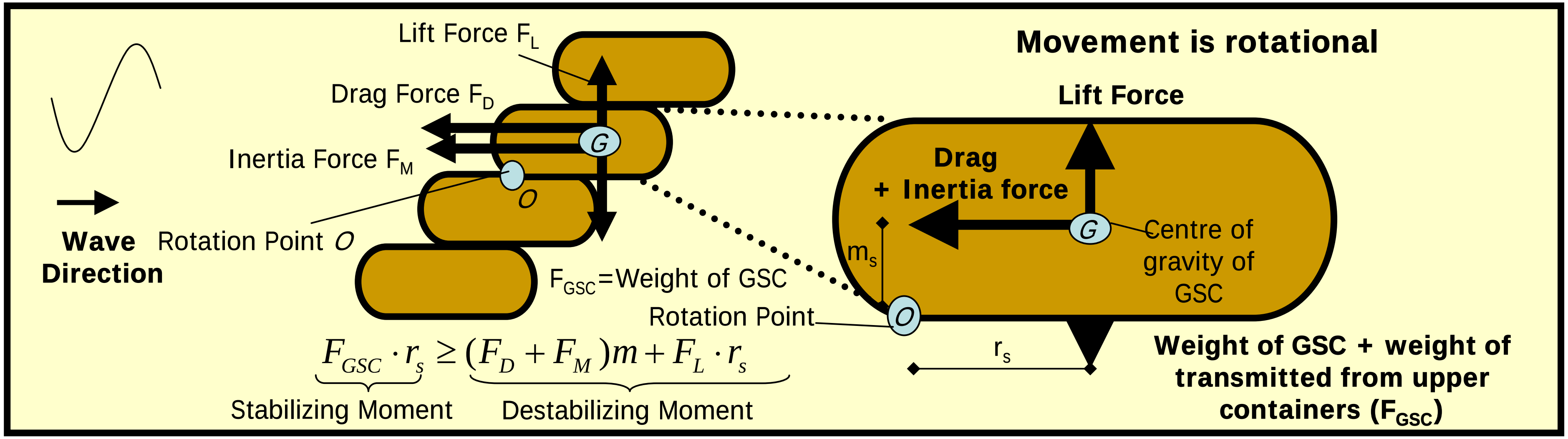
(b) Hydraulic Stability of a Sand Container against Sliding without Deformation

Increase of Exposed Areas for Drag and Uplift Force-Effect on Sliding Stability (2)

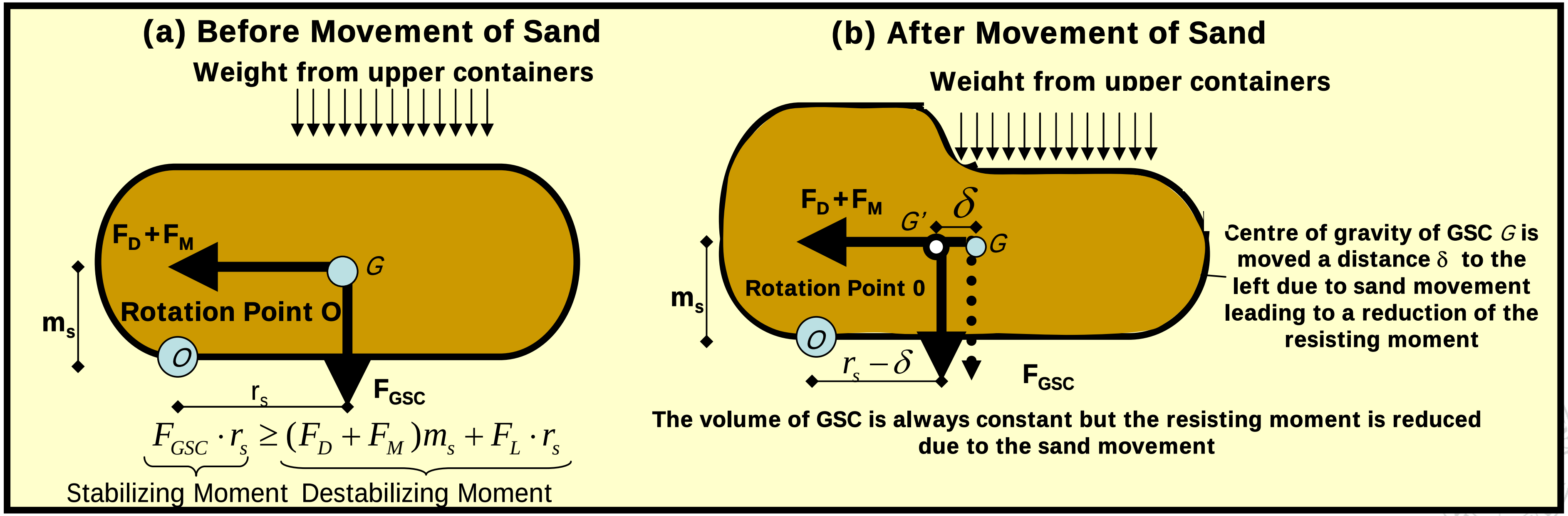


(c) Effect of the Internal Movement of Sand on the Sliding Stability of a Sand Container

Effect of Deformation on Overturning Stability



(a) Stability of a GSC against Overturning without Deformation

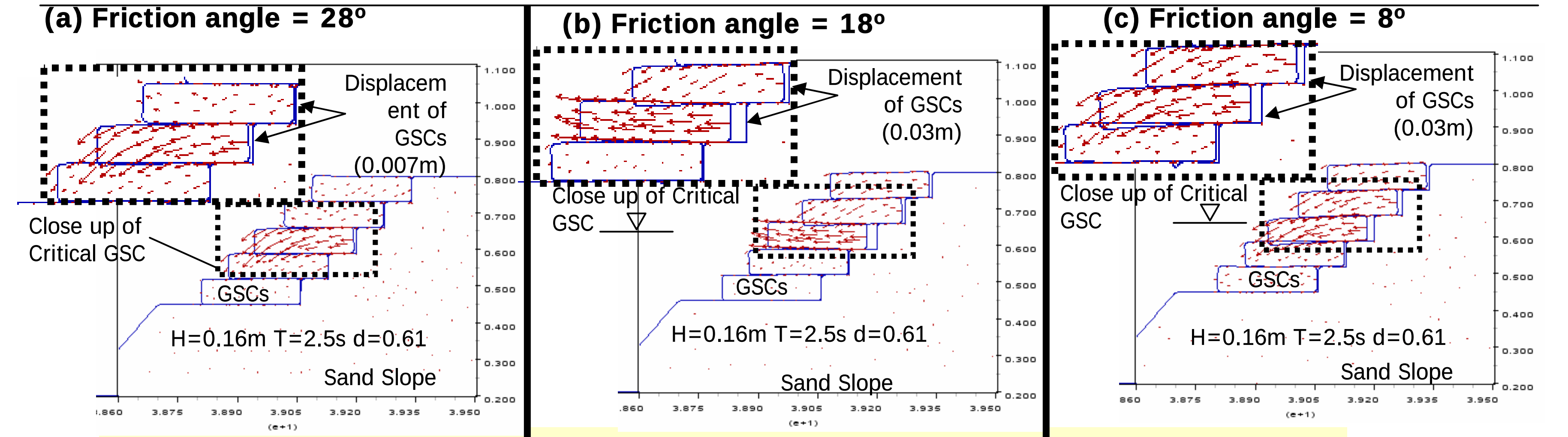


(b) Effect of the Internal Movement of Sand on the Overturning Stability of a Sand Container

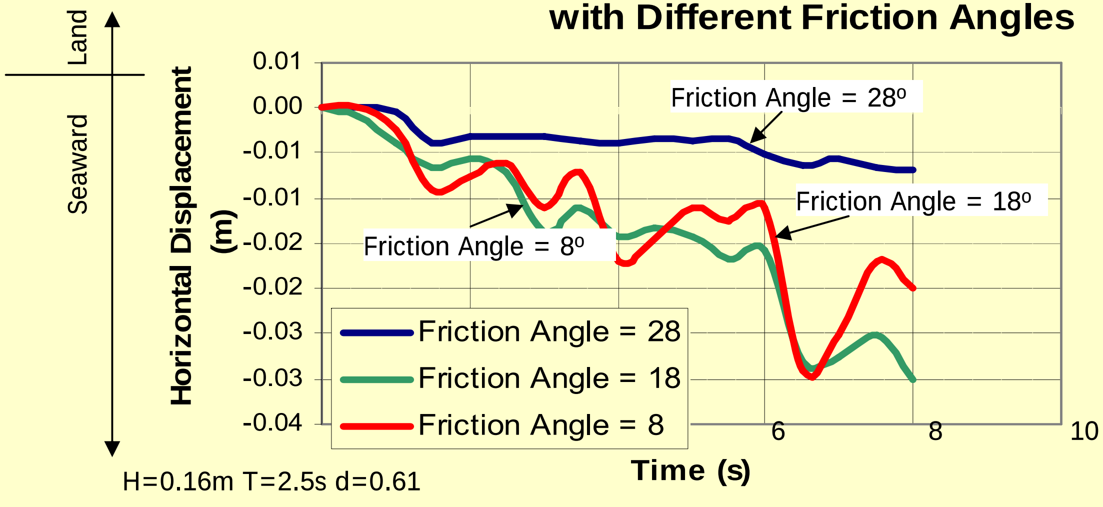
4.2.2.6 Effect of Friction Between GSCs on Hydraulic Stability

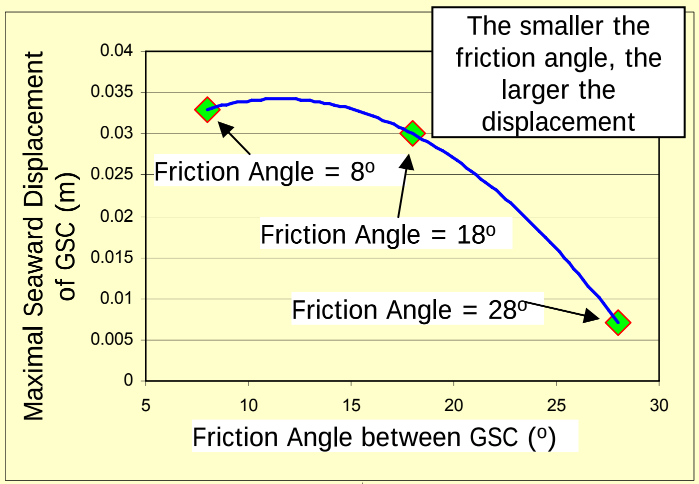
Effect of Friction between GSCs on the Hydraulic Stability of GSC-Structures (H=0.16m, T=2.5s and d=0.61m)

Position of GSCs after 4 Wave Cycles

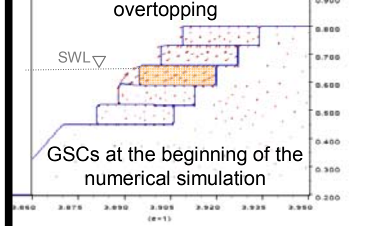
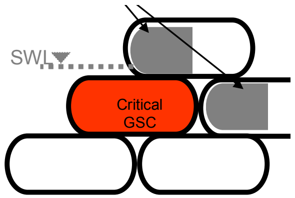
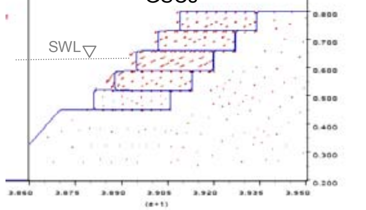
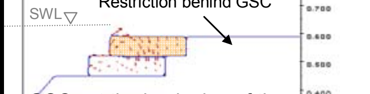
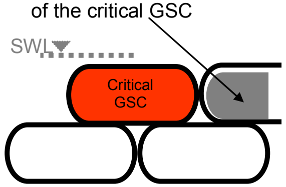
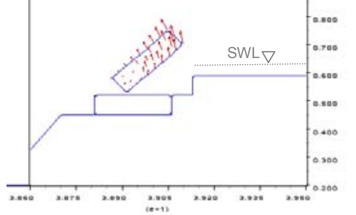
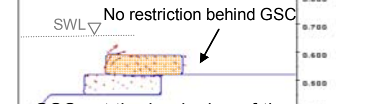
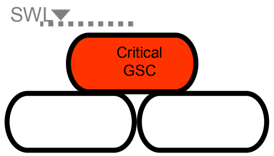
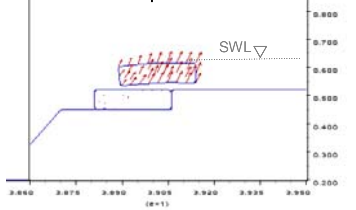


Comparison of Lateral Displacement of Critical GSCs with Different Friction Angles





Influence of Neighbouring Containers

Structure Sketch	Boundary Conditions	Displacements of GSCs
(a) Neighbouring Containers Above, Beneath and Behind		
GSC-structure with no overtopping  GSCs at the beginning of the numerical simulation H=0.08m, T=2.5s, d=0.61m	Contribution from neighbouring containers to the hydraulic stability of the critical GSC  Critical GSC is partially restricted on its rear and upper parts	After five wave cycles there is no displacement of the critical GSCs  H=0.08m, T=2.5s, d=0.61m
(b) Neighbouring Containers Beneath and Behind		
GSC-structure with overtopping Restriction behind GSC  GSCs at the beginning of the numerical simulation H=0.08m, T=2.5s, d=0.61m	Contribution from neighbouring container to the hydraulic stability of the critical GSC  Critical GSC is partially restricted only on its rear part	After one wave cycle the GSC is uplifted and upturned  H=0.08m, T=2.5s, d=0.61m
(c) Neighbouring Containers Only Beneath		
GSC-structure with overtopping No restriction behind GSC  GSCs at the beginning of the numerical simulation H=0.08m, T=2.5s, d=0.61m	No contribution from neighbouring  Critical GSC has no restrictions	After one wave cycle the GSC is displaced landward and uplifted  H=0.08m, T=2.5s, d=0.61m

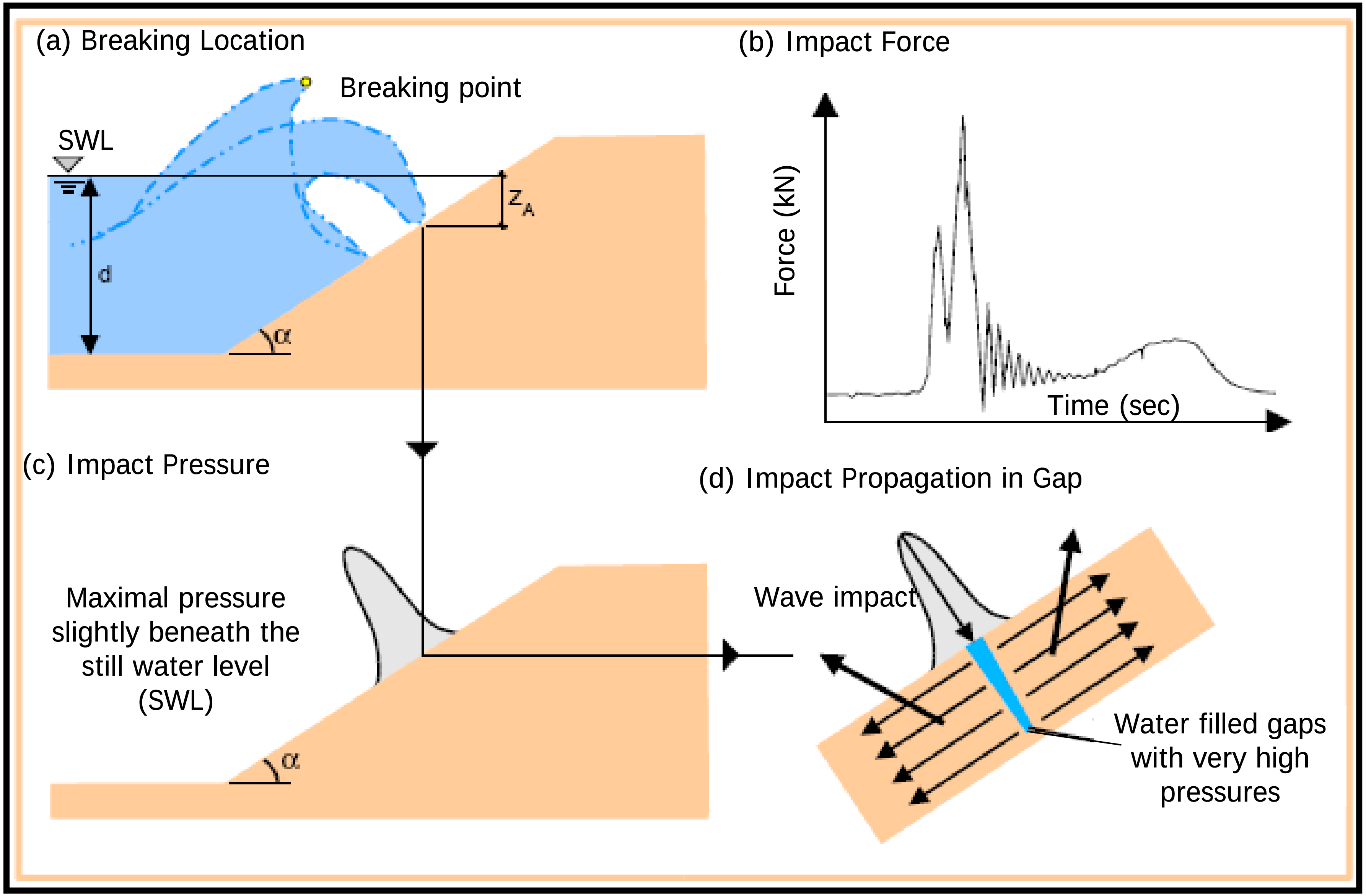
Videos

Crest GSC, Horizontal Restriction Behind H08m T2.5s d0.61m.avi

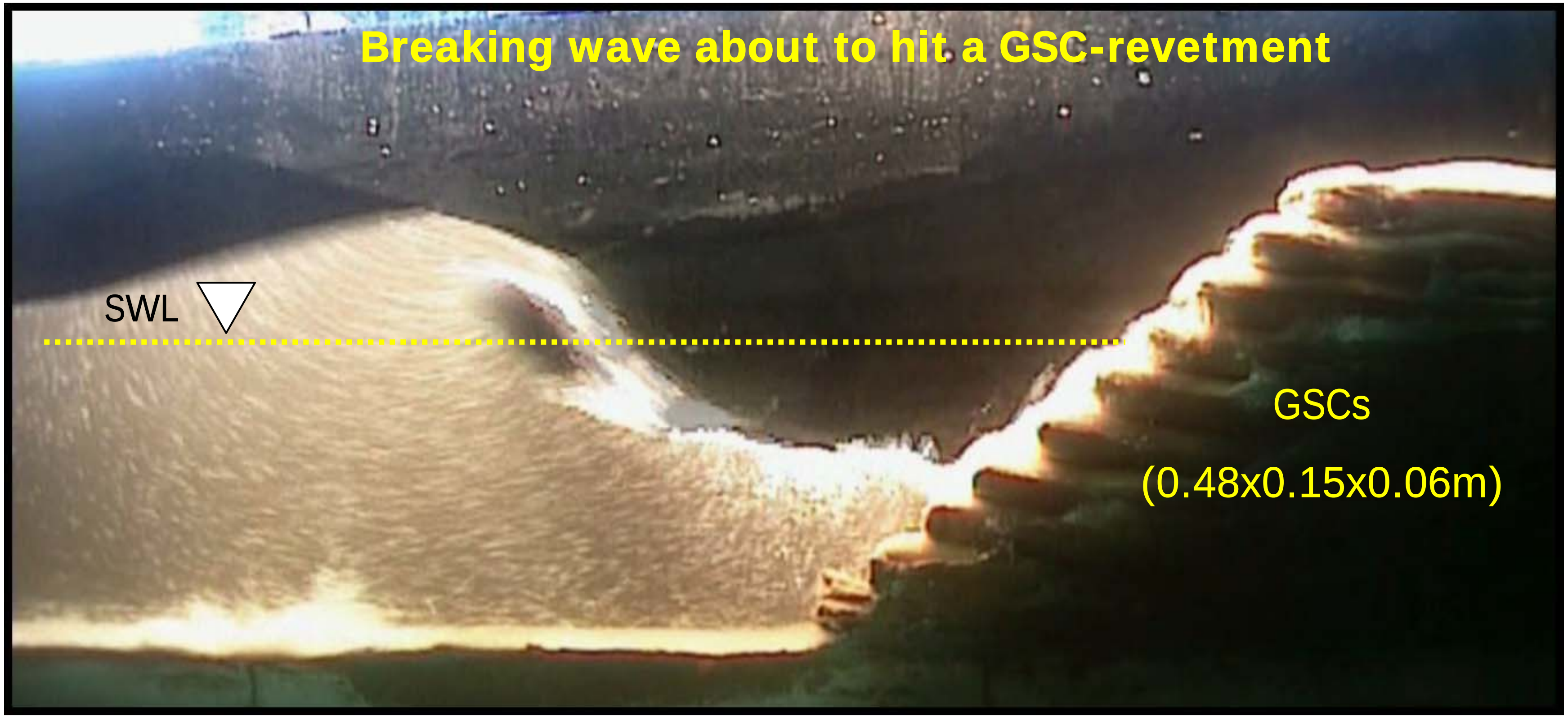
Crest-GSC No Restrictions H0.08m T2.5s d0.61m.avi

4.2.3 Effect of Breaking Wave Impact Forces on GSC-Stability

Position of the Problem: Breaking Wave Load on Dike Slope (definition sketches)

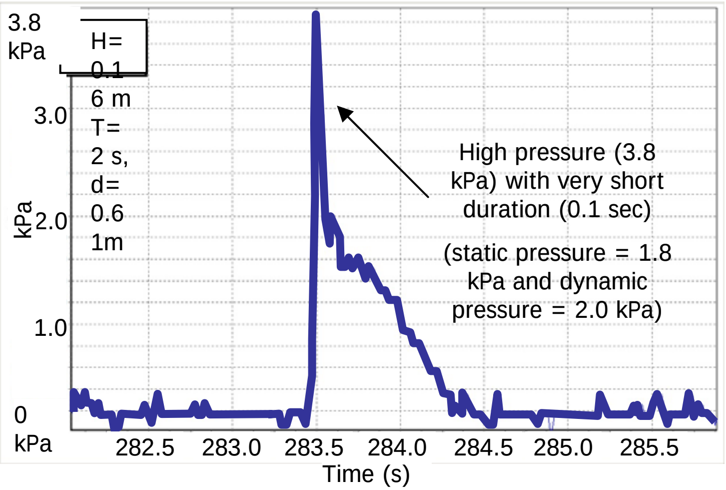


Breaking Wave on a GSC-Structure in the LWI-Flume



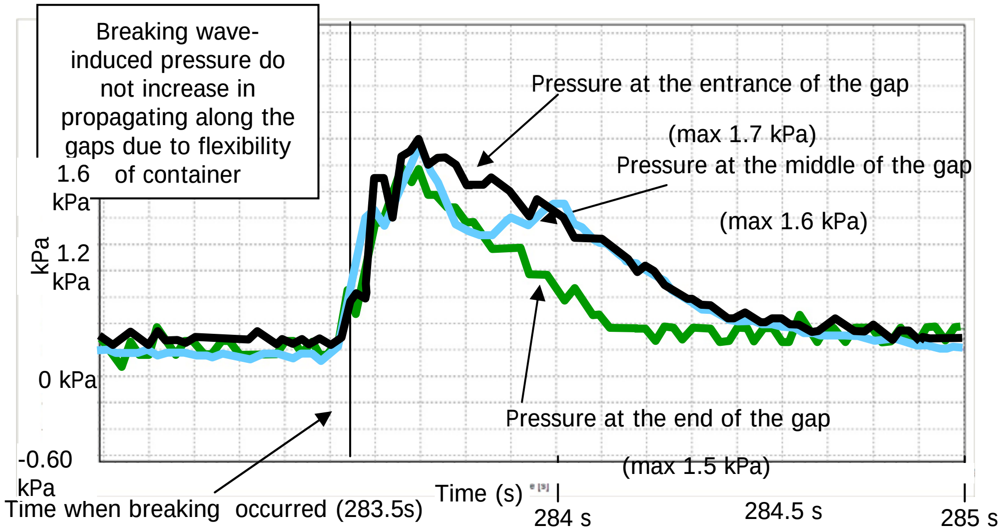
Pressure Propagation along a Gap Between Geotextile Sand Containers

(a) Breaking Wave-Induced Pressure on the Front of GSC-Revetment



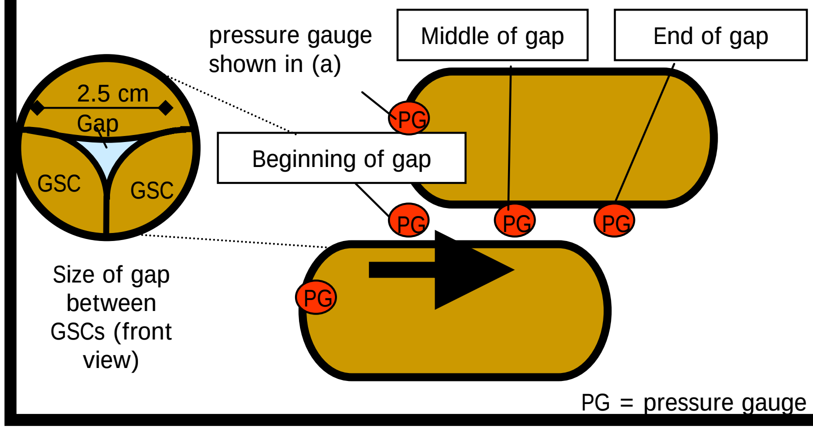
Recorded from exp no. 26010510 H=0.16m, T=2.5sec, d=0.61m

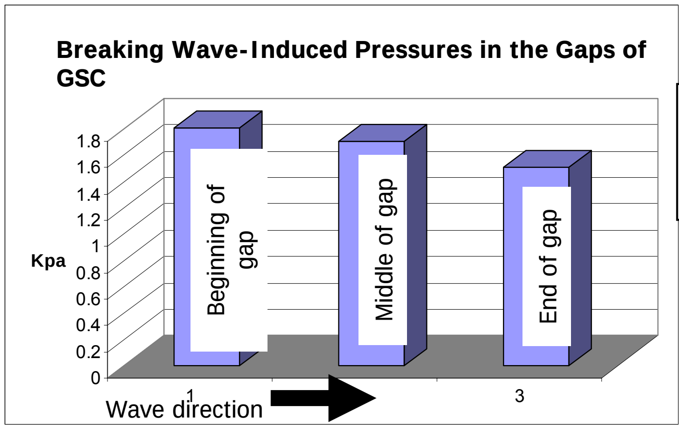
(b) Breaking Wave-Induced Pressure Along the Gap between Geotextile Sand Containers



Recorded from exp no. 26010510 H=0.16m, T=2.5sec, d=0.61

(c) Comparison of Wave-Induced Pressure Recorded at the Entrance, Middle and End of Gap between Geotextile Sand Containers

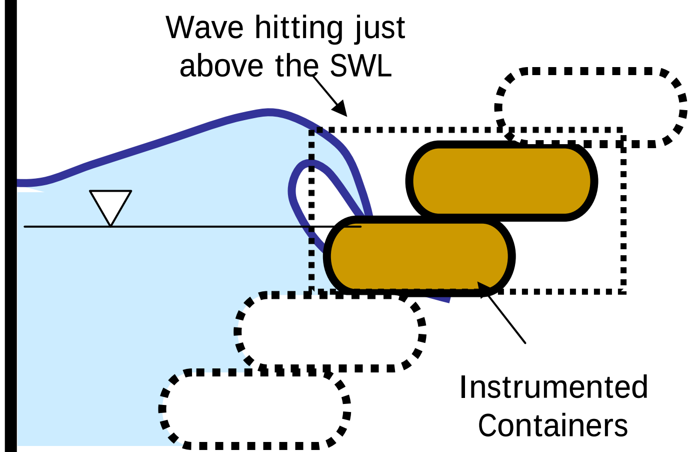




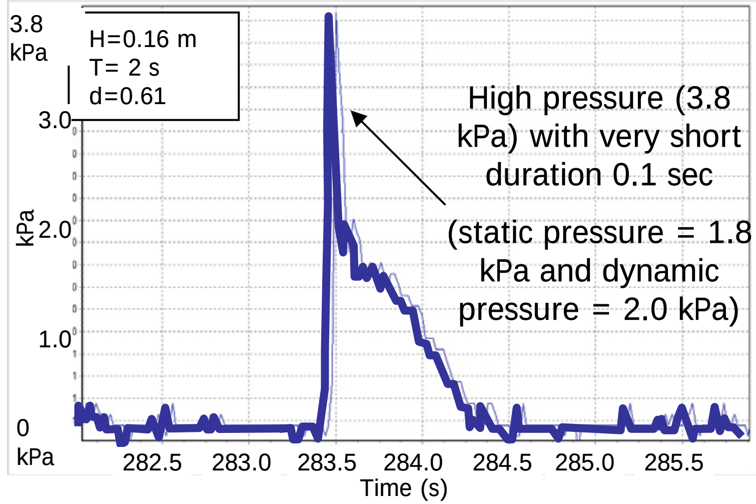
Pressures along the gap between containers are reduced (dampening due to flexibility of containers)

Breaking Wave Impact Loads on a GSC-Structure (definition sketches)

(a) Breaking Wave on GSC-Revetment

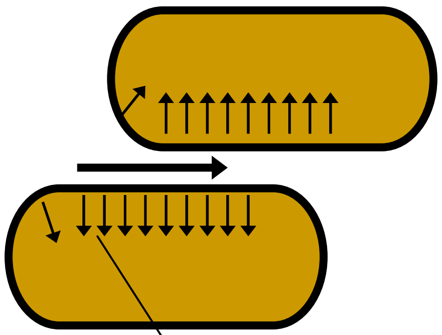


(b) Breaking Wave-Induced Pressure on Front of GSC-Revetment



Recorded from exp no. 26010510 H=0.16m T=2.5sec d=0.61m

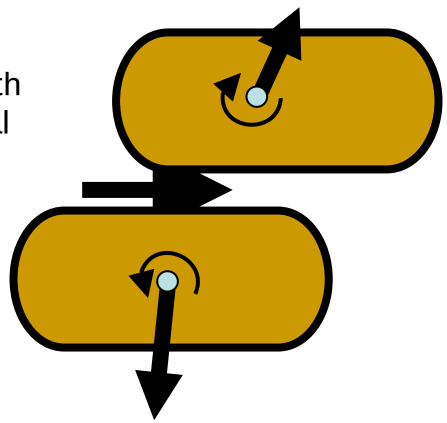
(c) Immediately After the Impact Load



Breaking wave-induced pressures propagate through the gaps

(d) Resultant Forces and Moments

Forces and moments with opposite direction. Total forces and moments depend of the wave-induced pressure propagation inside the gaps



- Impact pressure are damped along the gaps between GSCs
- Impact load less critical than down rush phase of non-breaking waves

4.2.4 Concluding Remarks

Concluding Remarks on Relevant Processes During Up- and Down-Rush

- Down-rush phase most critical for stability: max. seaward force occurs at end of down rush phase.
- Most critical location for stability of slope GSC is just below SWL.
- Deformations of GSCs are essentially due to internal sand movement. They essentially depend on the sand fill ratio which needs more control and regulation than in the past.
- Effect of deformation on the stability of GSCs can be primarily explained by

    (i) Decrease of contact area between GSCs due to uplift process

    (ii) Increase of impact area of drag force and lift force

- Friction between GSCs strongly affect stability. We must better account for this parameter than in the past.

- ⇒ **Cobras:** can simulate Wave-Structure Interaction
- ⇒ **Cobras-UDEC:** has shown surprisingly good agreement with experimental results.
- ⇒ **Cobras: c**an simulate the flow through a GSC-structure. Flow through the structure is governed by the gaps between GSCs.
- ⇒ **Friction between GSCs :** strongly affects the stability of GSC-structures.
- ⇒ **Critical areas are for GSC:** just below the still water level and at the crest of the structure.
- ⇒ **A coupled RANS-VOF with a FEM-DEM:** huge potential as an engineering tool to investigate the stability of coastal structures as well as wave-structure interaction.