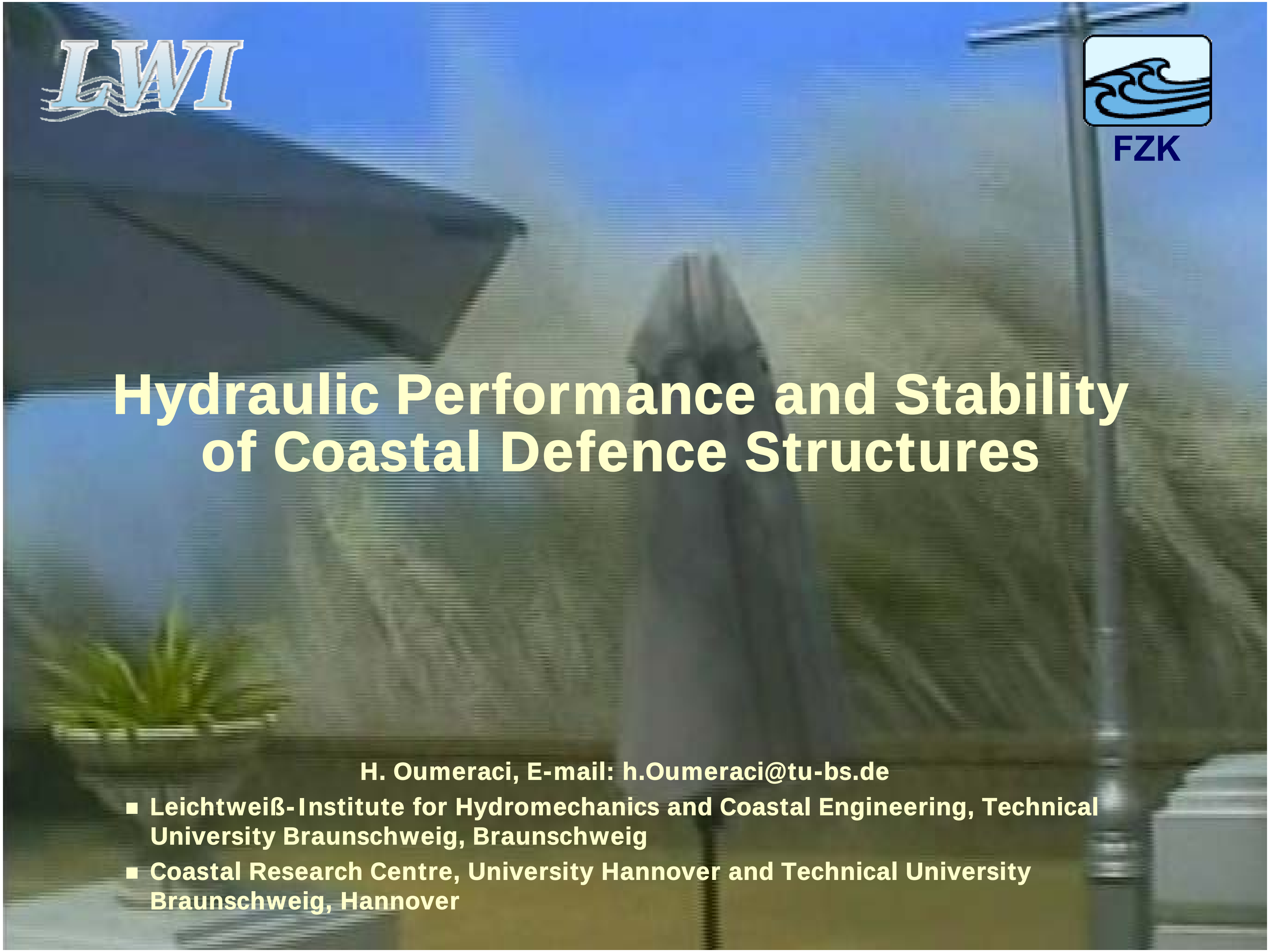

Hydraulic Performance and Stability of Coastal Defence Structures

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- Coastal Research Centre, University Hannover and Technical University Braunschweig, Hannover

Outline

- Rubble Mound Structures and Breakwaters:
  - Wave-Induced Internal Flow and Hydraulic Performance
  - Effect of Core Permeability on Hydraulic Stability and Performance
- Hydraulic Performance of an Artificial Reef with Rectangular Shape
- Hydraulic Performance of Wave Absorbers
  - Submerged Wave Absorbers
  - Surface Piercing Wave Absorbers
- Submerged Wave Absorbers as Artificial Reefs for Coastal Protection
- Soft Wave Barriers for Coastal Protection
- Geotextile Structures for Coastal Protection

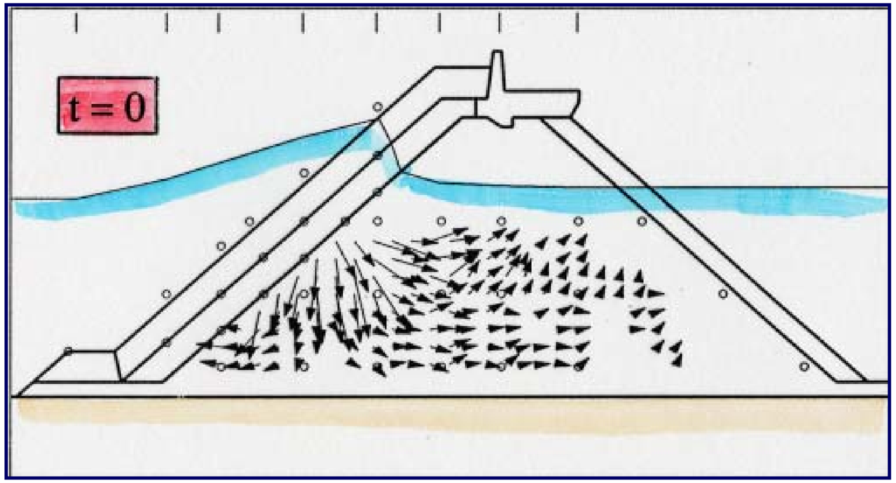
Rubble Mound Structures and Breakwaters

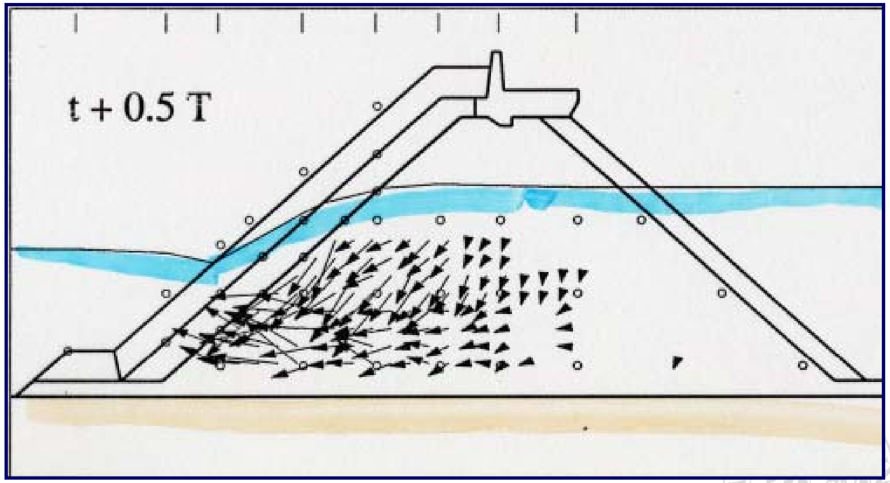
Wave-Induced Internal Flow and Hydraulic Performance

References:

- Muttray, M. (2000): Wave motion at and in rubble mound breakwaters-large-scale model and theoretical investigation, PhD-Thesis, TU Braunschweig 282p. (in German)
- Muttray, M., Omeraci, H. (2005): Theoretical and empirical study on wave damping inside a rubble mound breakwater, *Coastal Engineering* vol. 52 .pp. 709-725.

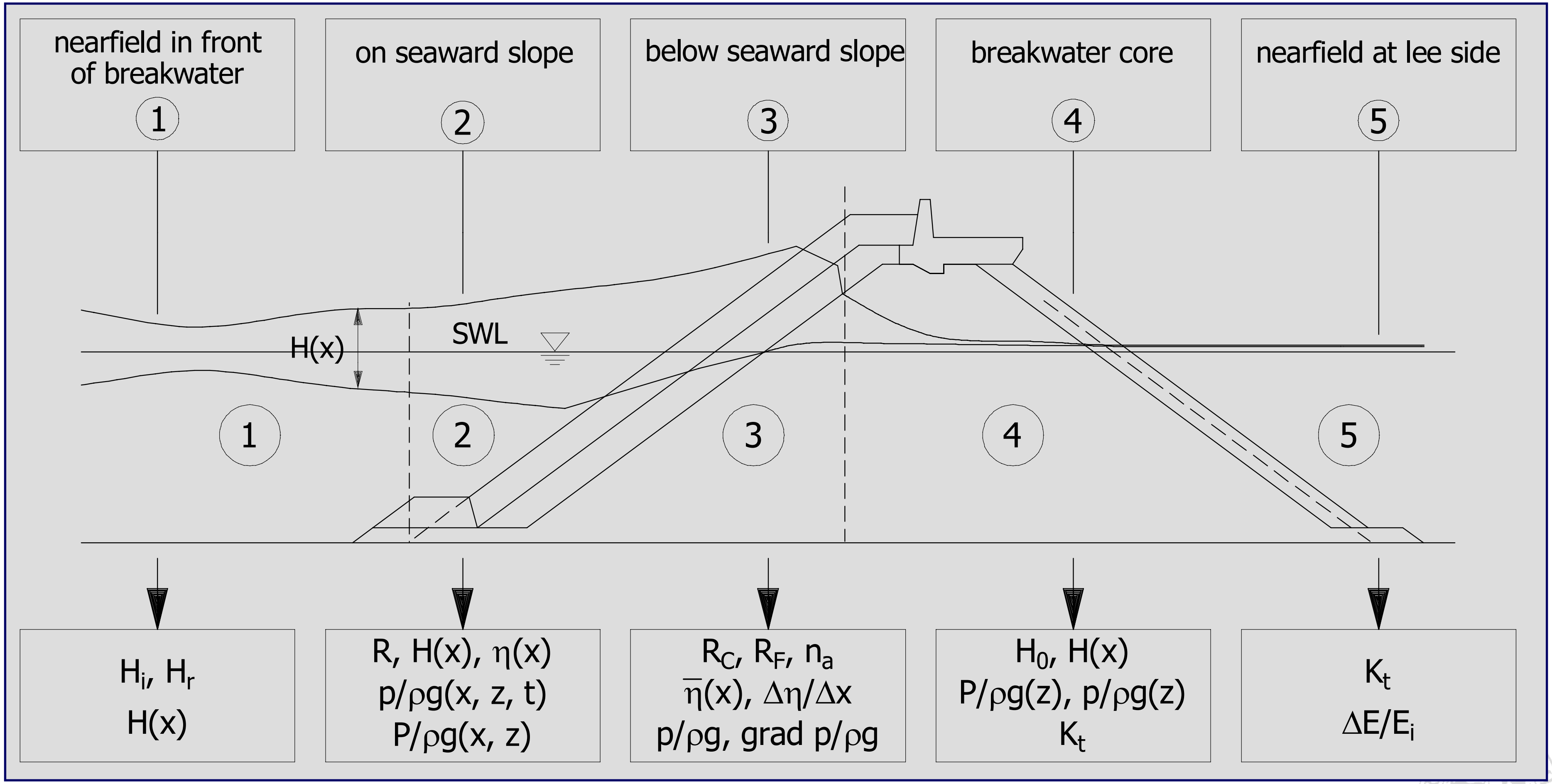
Rubble Mound Breakwater: Model Construction in GWK



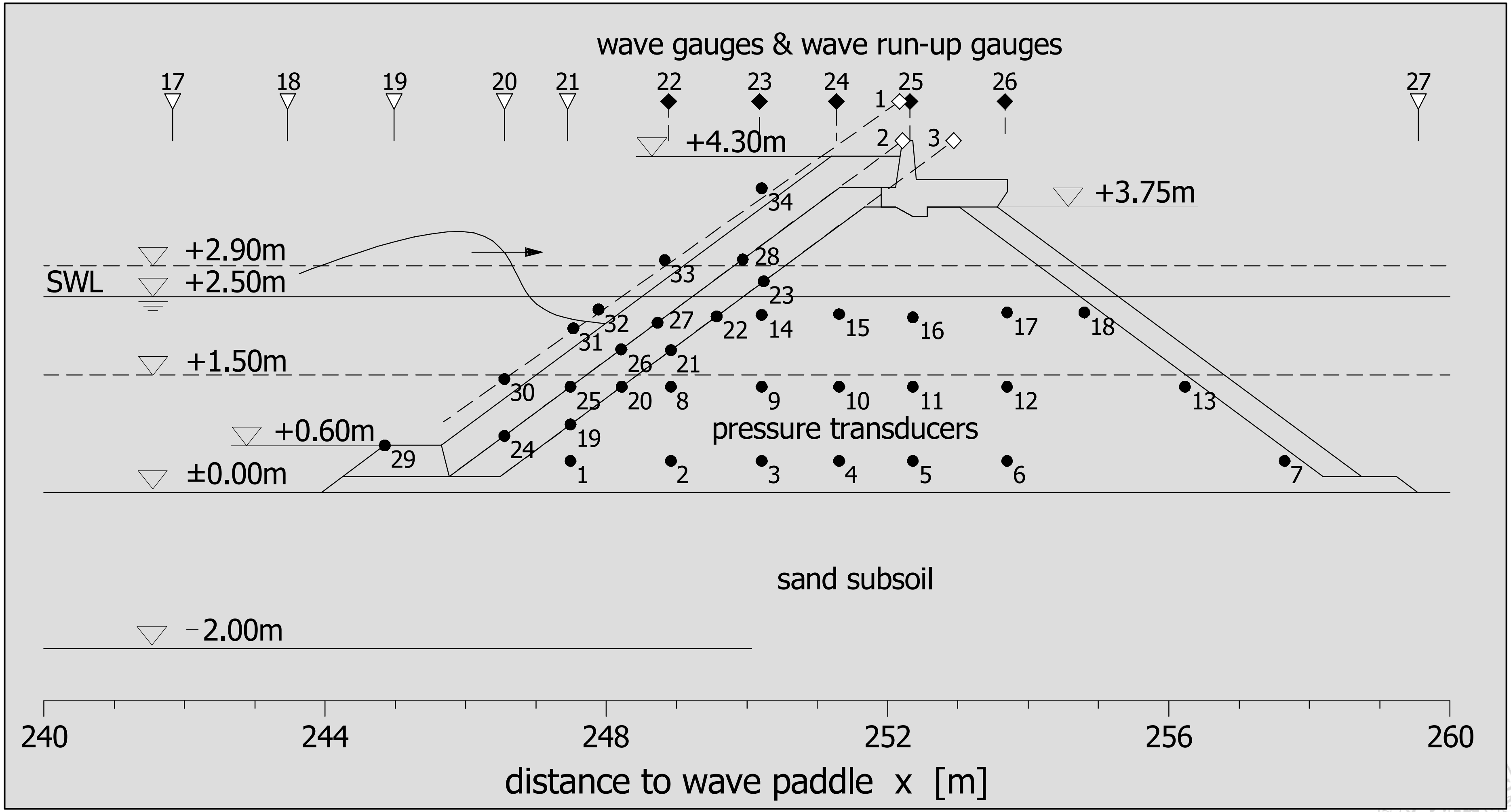


h = 4,50 m
H = 1,00 m
T = 6,00 s

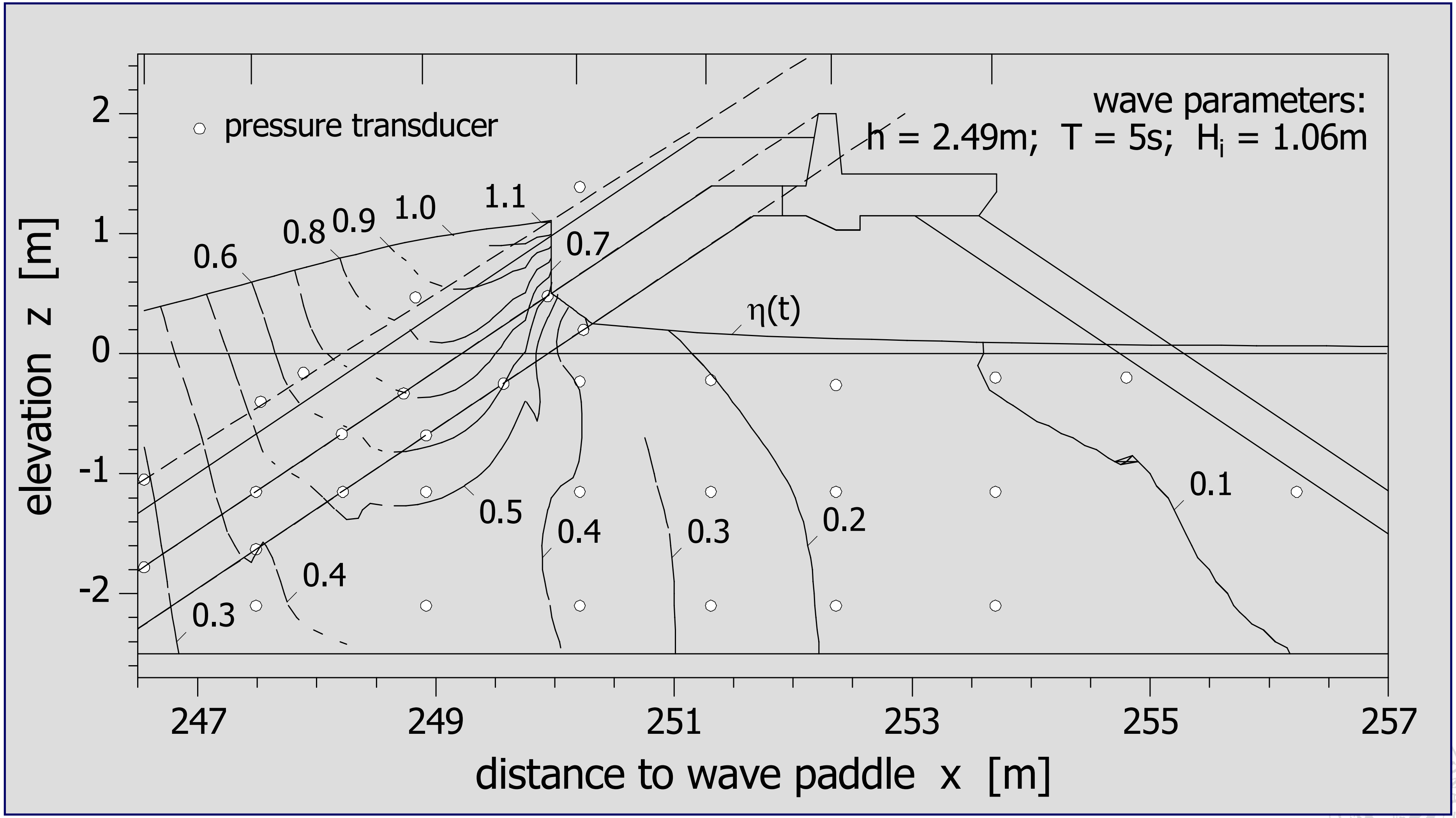
Research Strategy for Rubble Mound Breakwaters



Experimental Set-Up for Rubble Mound Breakwater Model



Wave-Induced Pore Pressure Field

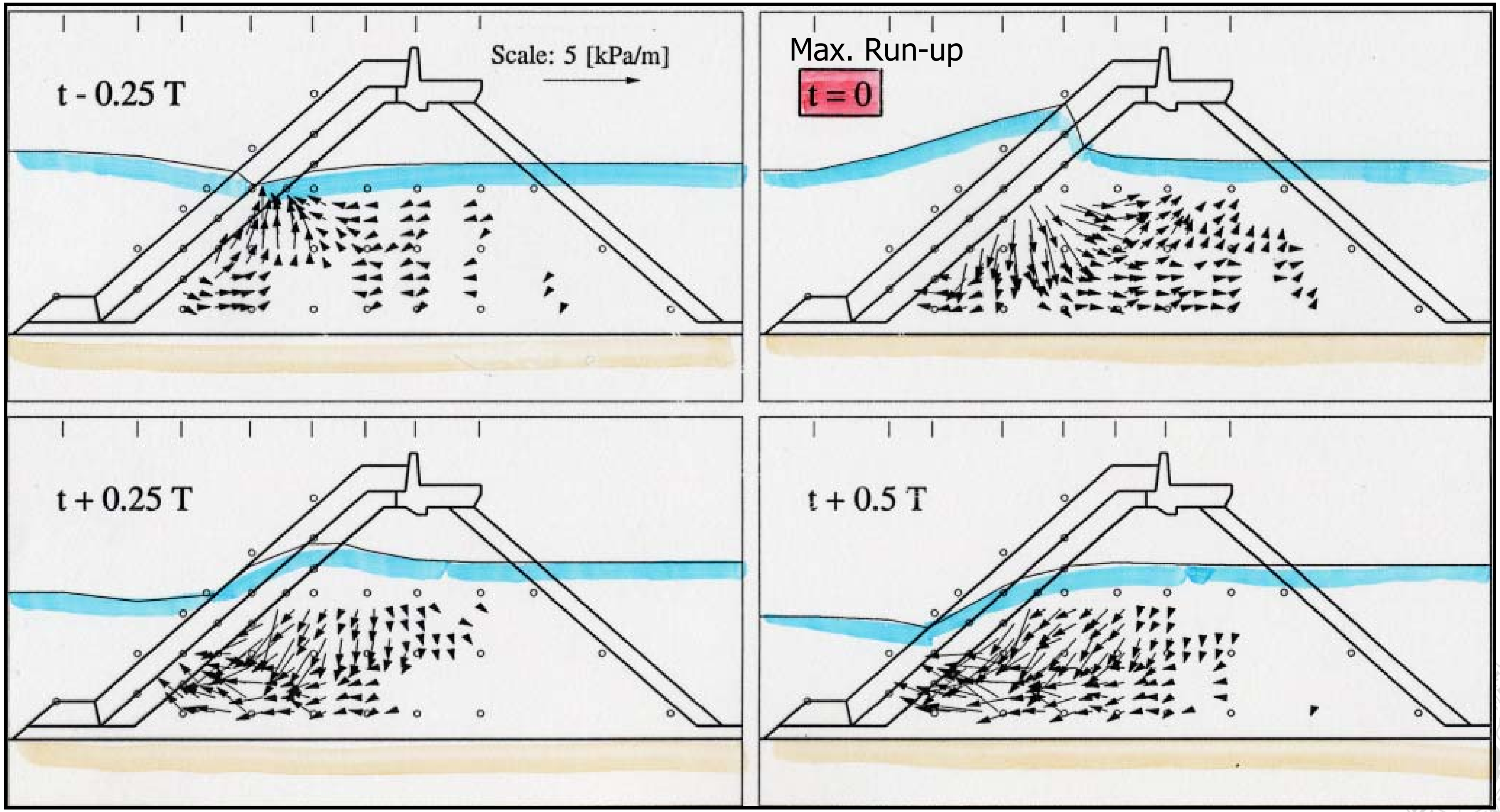


Internal Wave-Induced Pressure Gradient

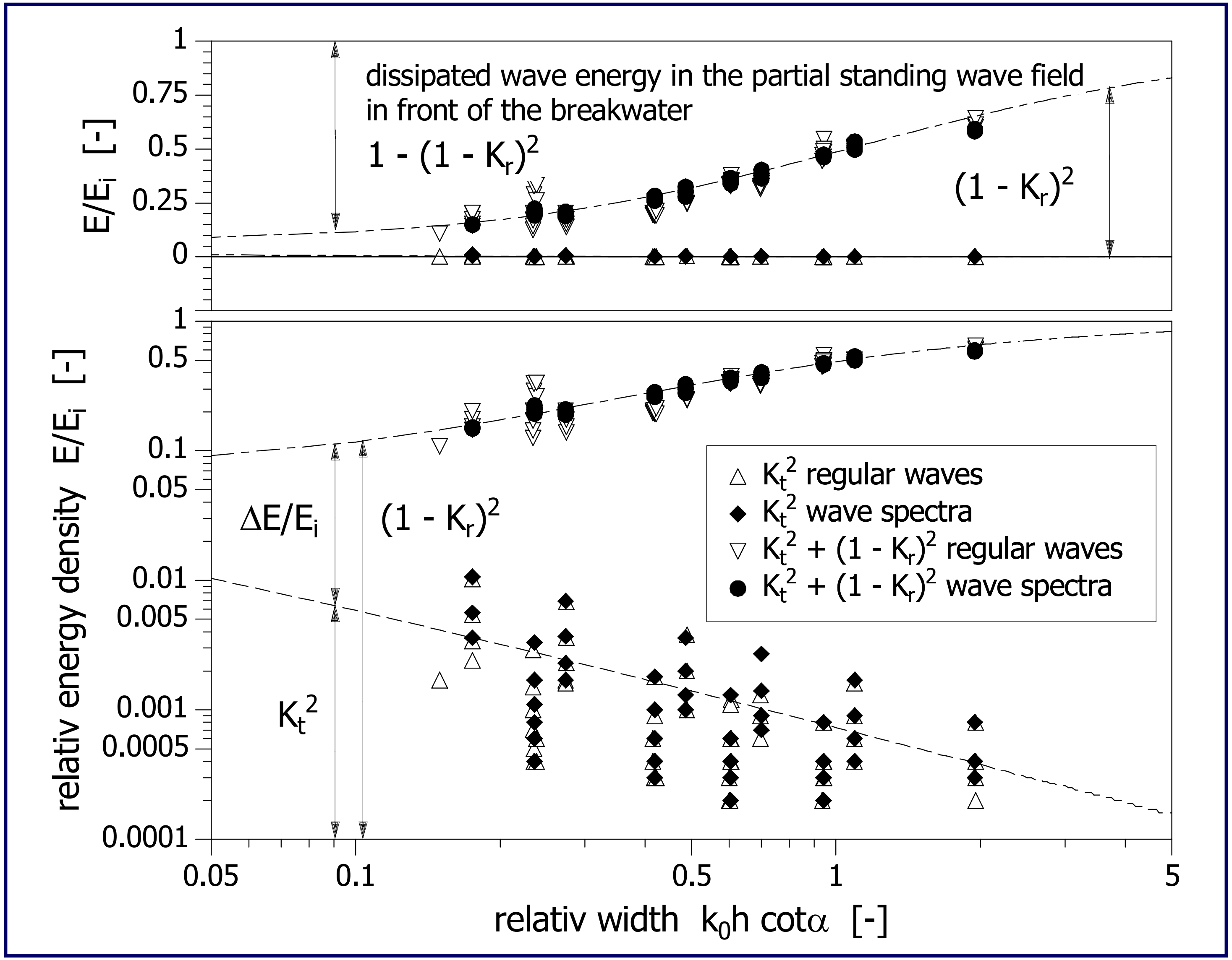
Regular Waves

max. Wave Run-up: t = 0 [s]

Water Depth : d = 4,50 [m]
Wave Height : H = 1,00 [m]
Wave Period : T = 6,00 [s]



Wave Energy Dissipation at and in the Breakwater

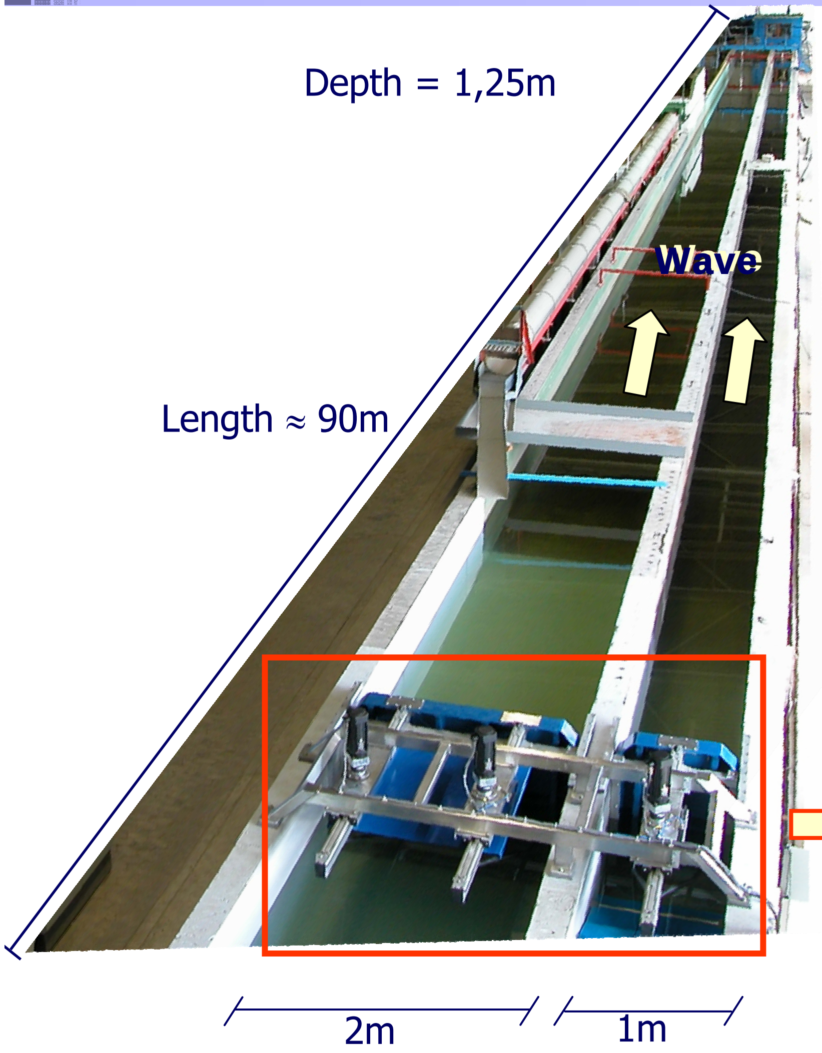


Effect of Core Permeability on Hydraulic Stability and Performance of Rubble Mound Breakwater

References:

- Oumeraci, H.; Kortenhaus, A.; Werth, (2007): Stability and Hydraulic Performance of a conventional rubble mound breakwater and breakwater with sand in geo containers. Submitted to ASCE Coastal Structure, Conf. Venice.

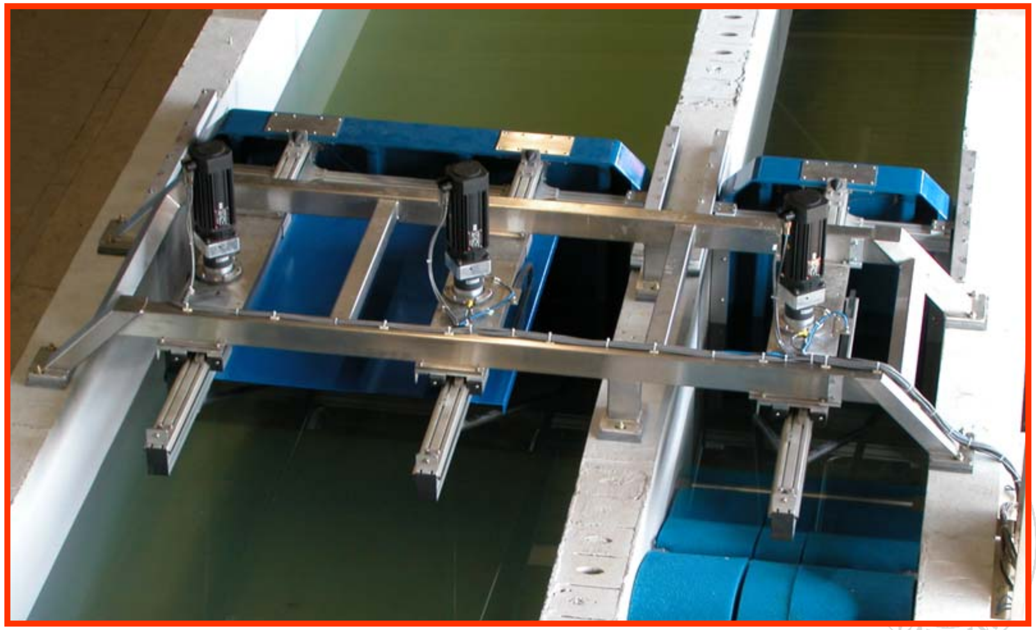
Twin-Wave Flume at Leichtweiß Institut



(a) General bird view of twin-flume

- Regular waves: up to H= 30cm
- Random wave: up to H_S= 20cm
- Solitary waves: up to H= 30cm

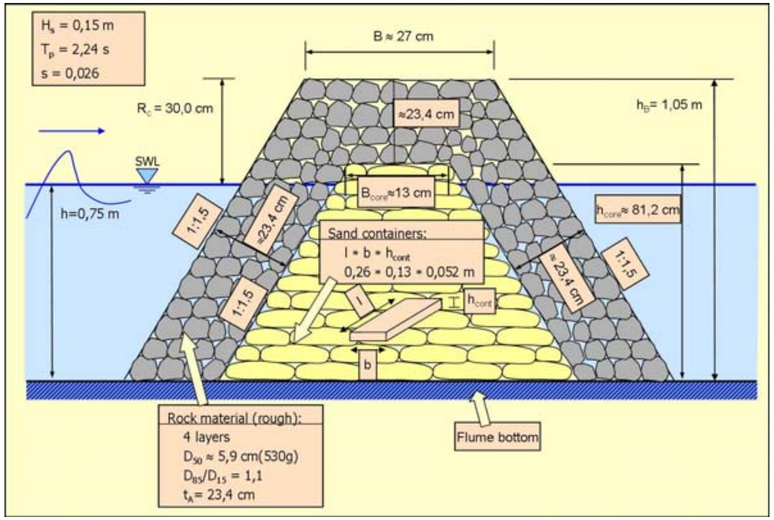
b) Twin-Wave Paddle (Synchron or independent)



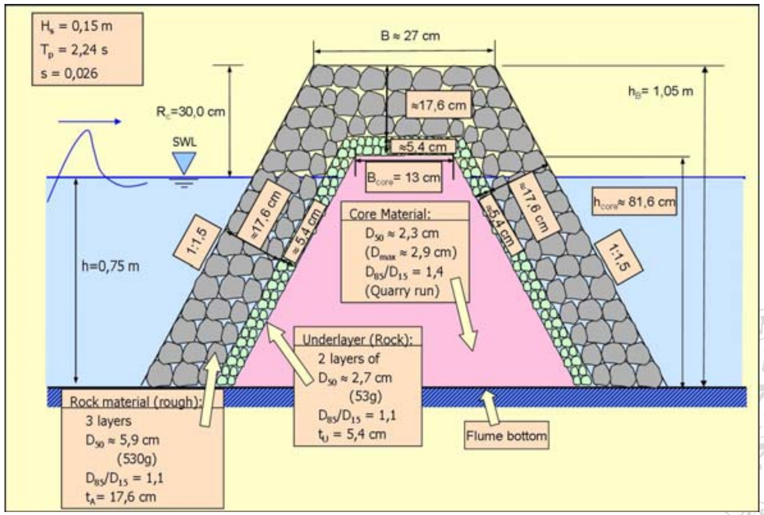
Geo-Core and Conventional Rubble Mound Breakwater Models in Twin-flume

(a) Model Breakwaters in the Twin-flume

(b) Geo-Core Breakwater model in the first flume



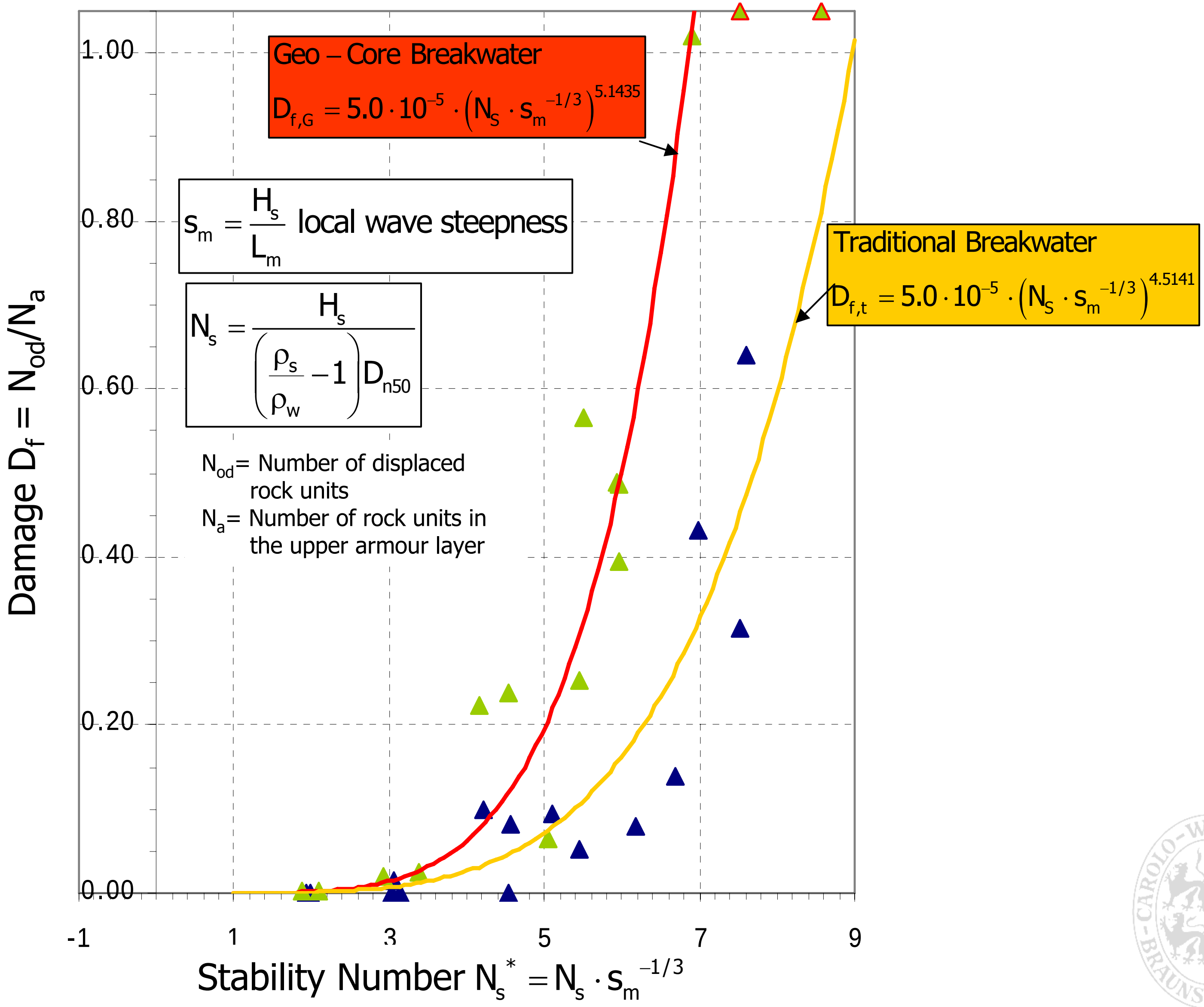
(c) Conventional Breakwater model in the 2nd. flume



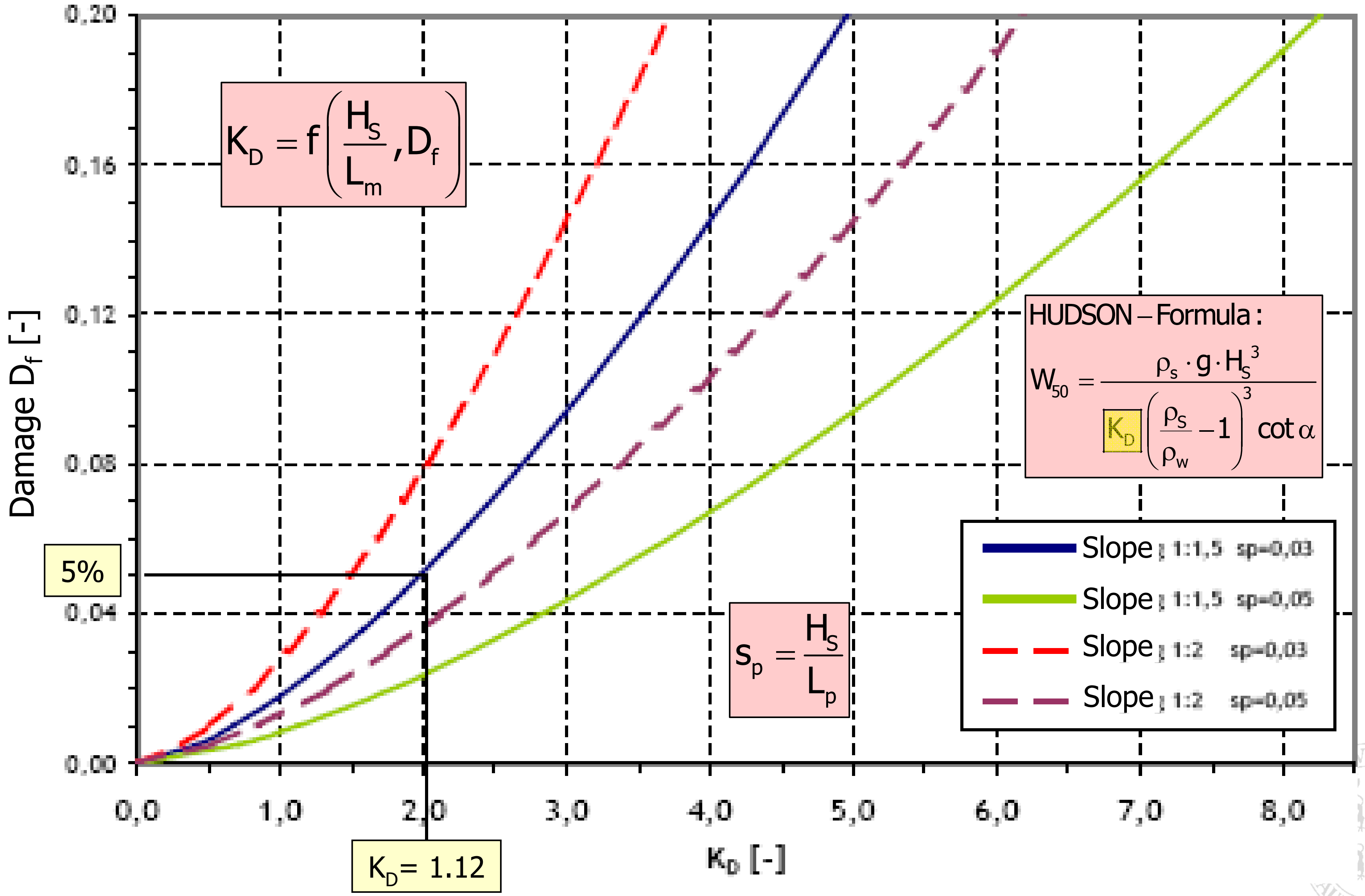
Permeability Model Tests

Mode of Placement	Description	Darcy´s permeability coefficient k value [m/s]
	GSC-structure made of geotextile sand containers placed **randomly**	**2.412 x 10^{-2}**
	Structure made of gravel	**3.881 x 10^{-1}**

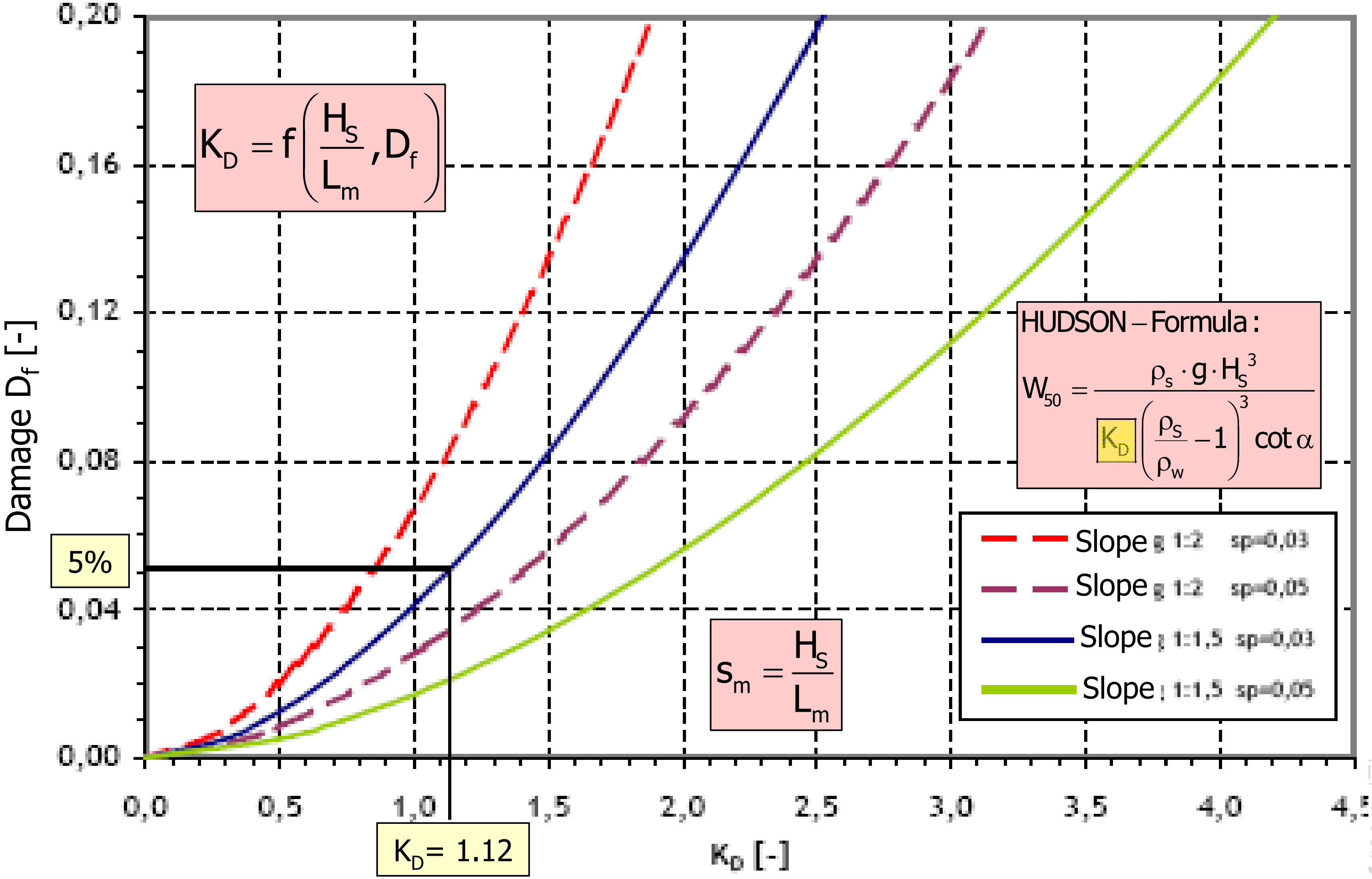
Stability Number: Geo-Core vs. Traditional Breakwater



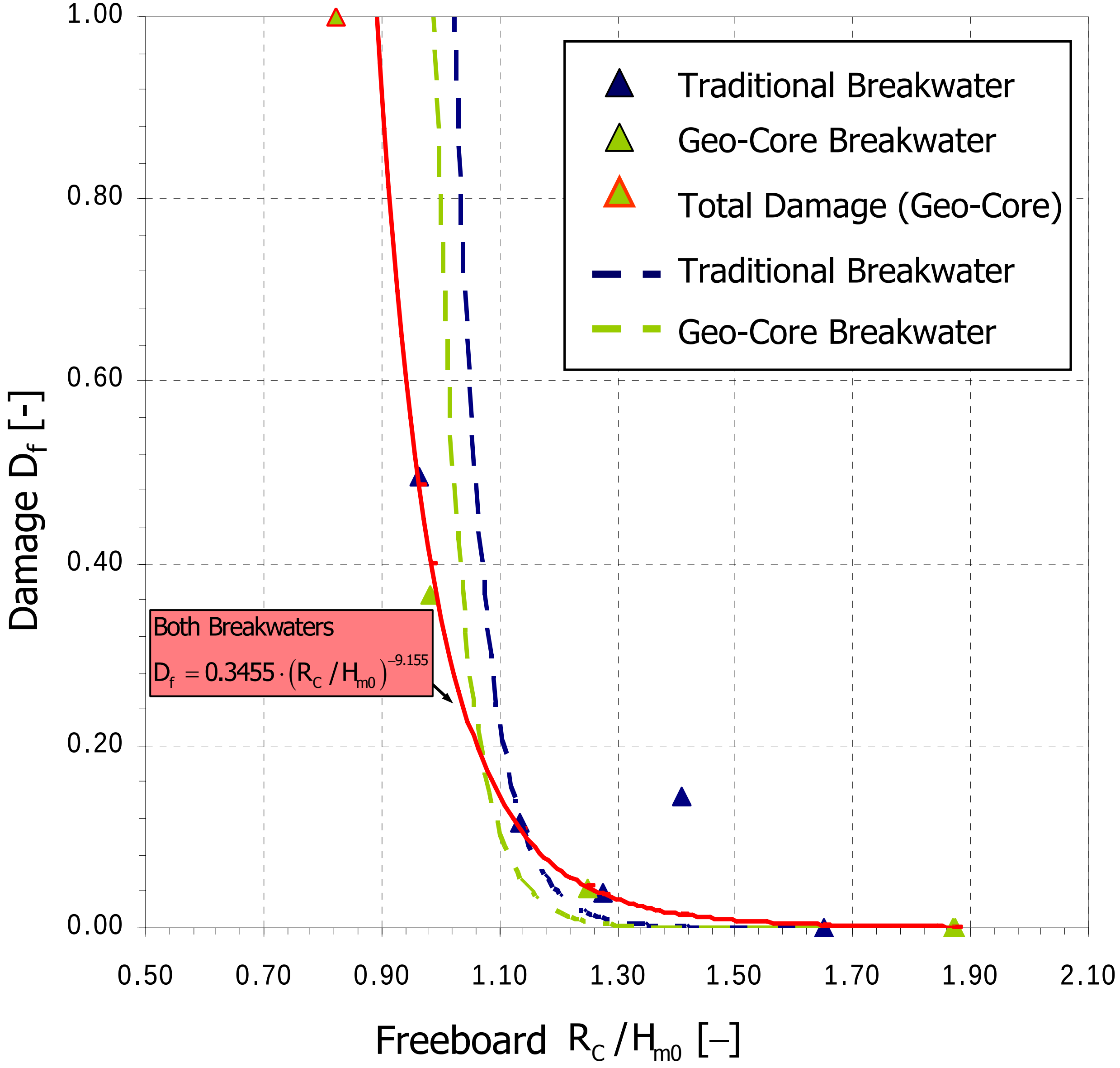
K_D – Value in HUDSON-Formula for Traditional Breakwater



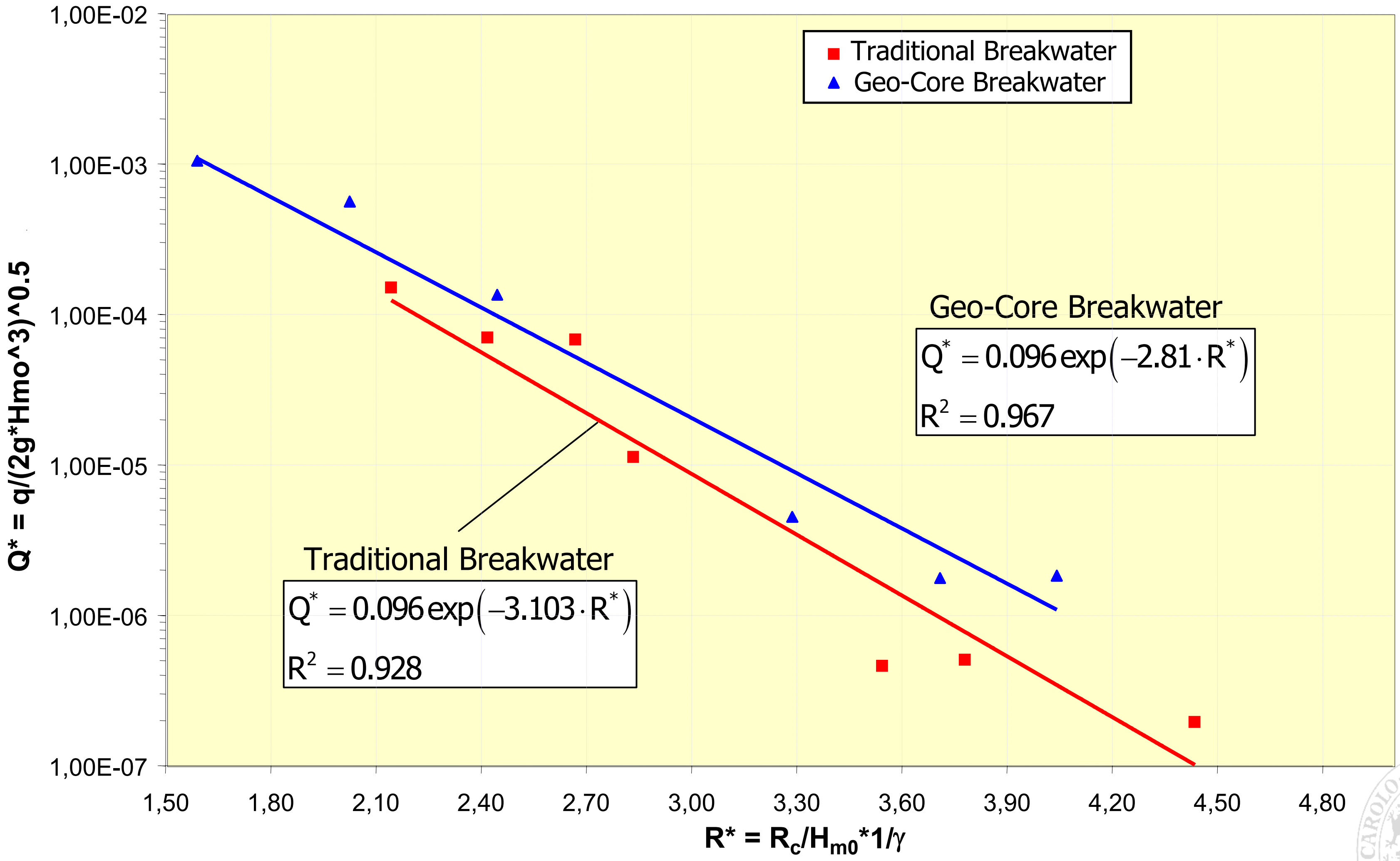
K_D – Value in HUDSON-Formula for Geo-Core Breakwater



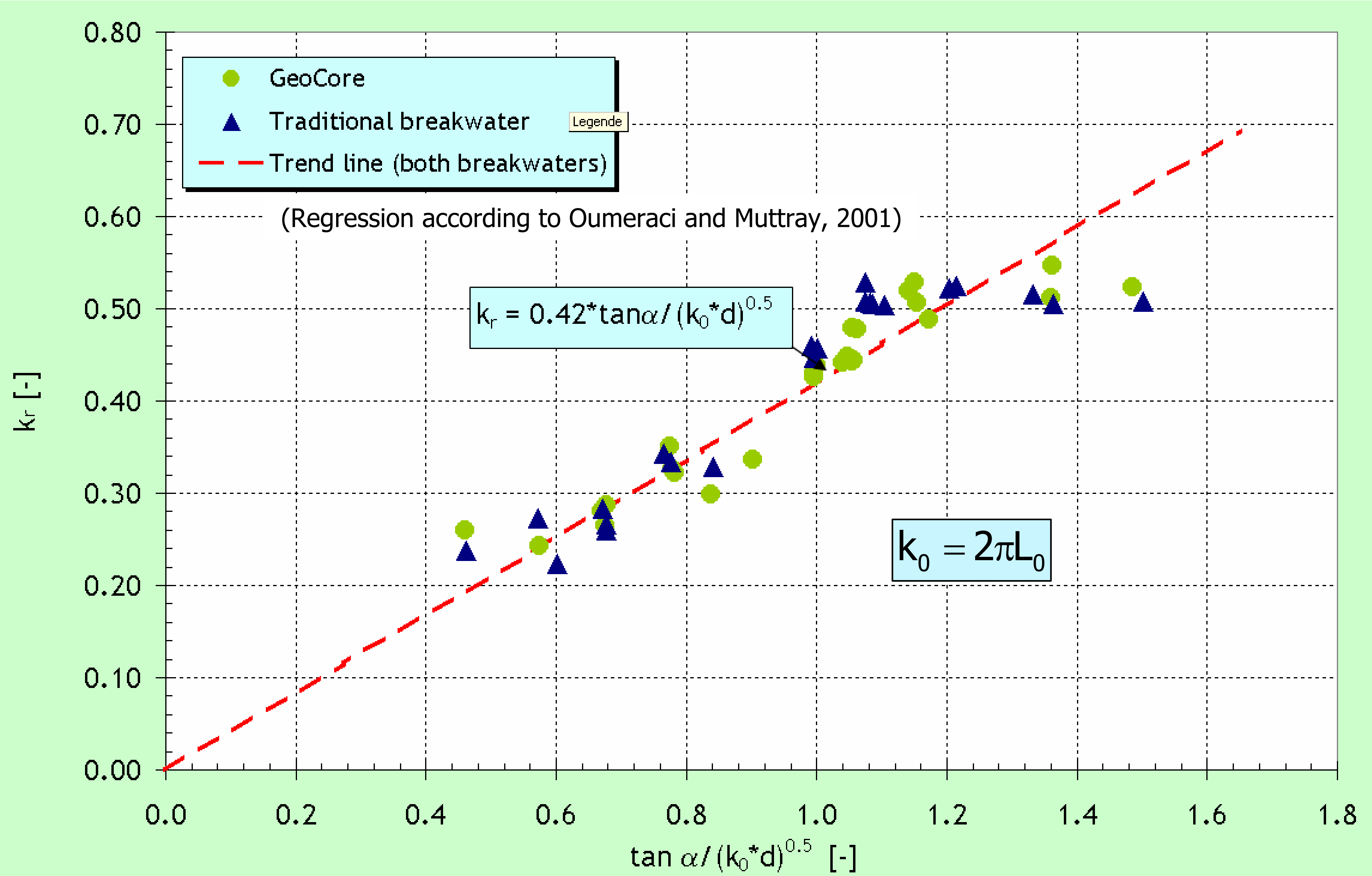
Stability Number for the Rear Side



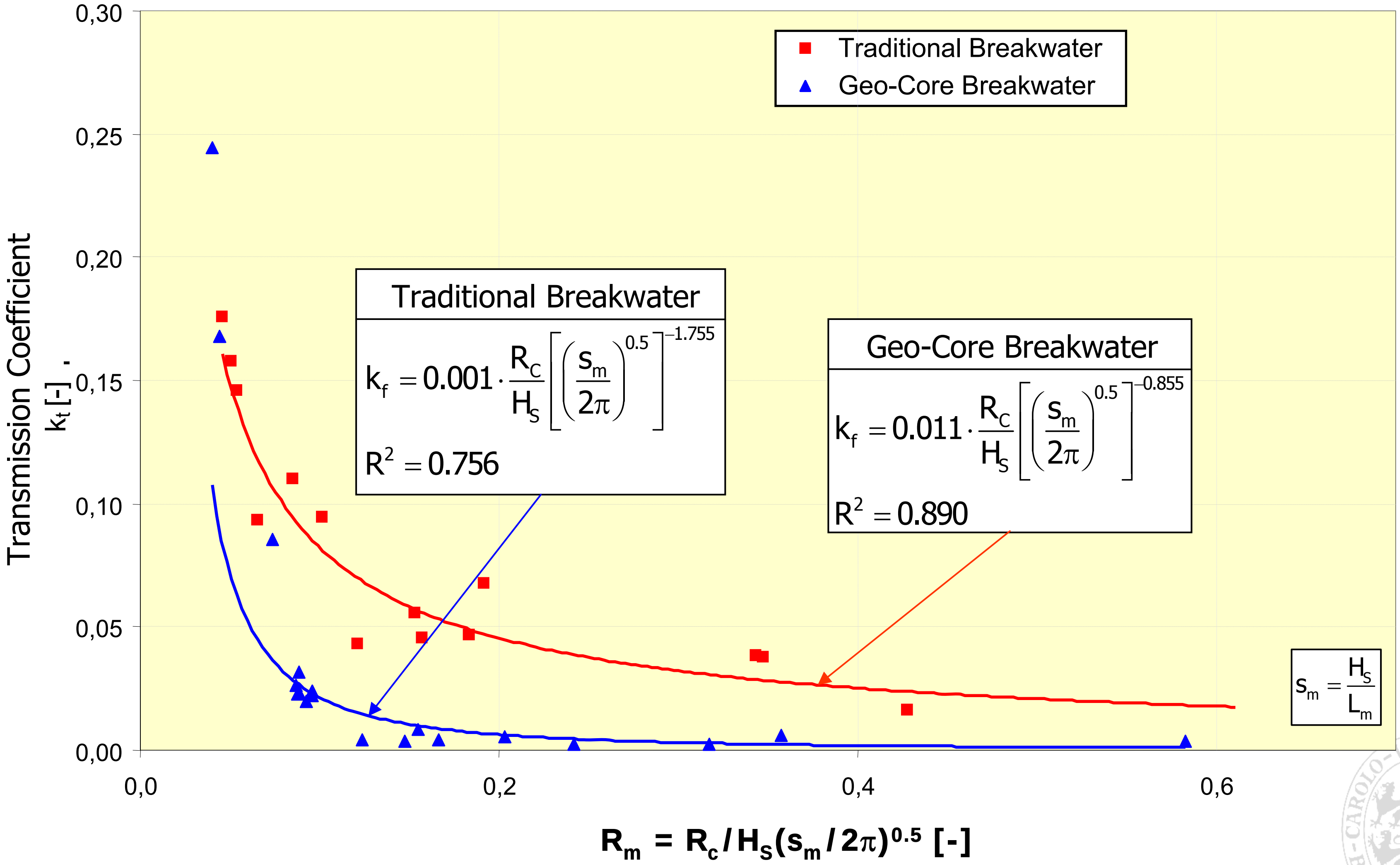
Wave Overtopping Performance



Wave Reflection Performance



Wave Transmission Performance

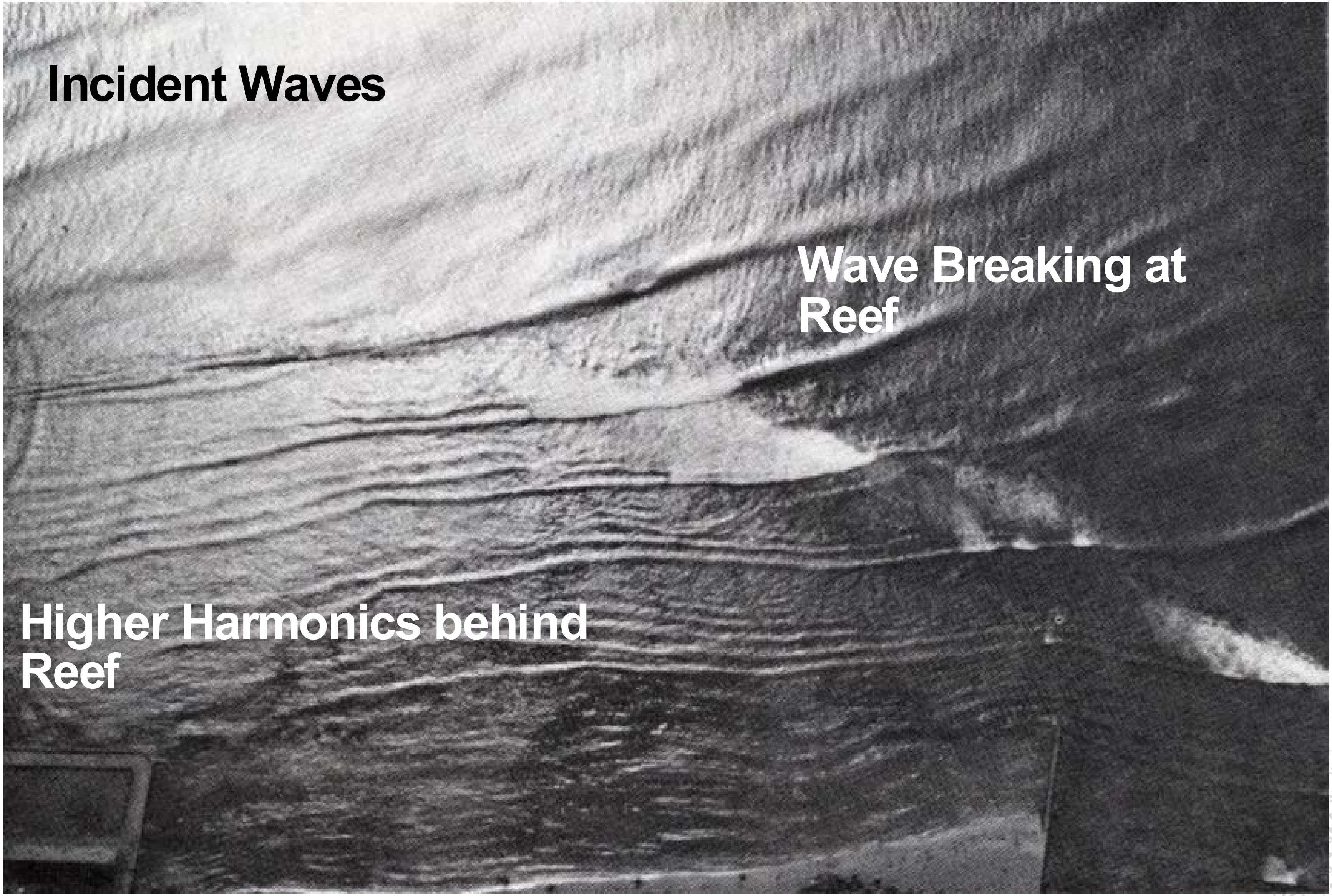


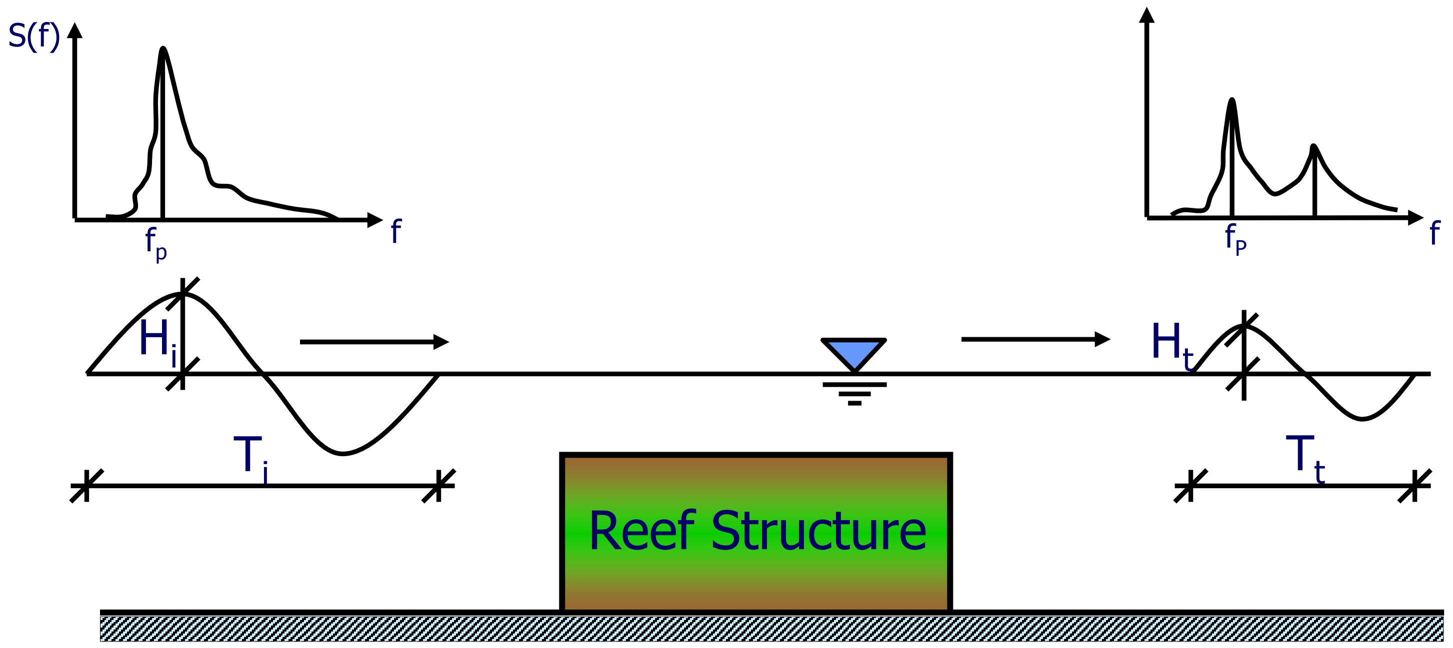
Hydraulic Performance of an Artificial Reef with Rectangular Shape

References:

- Bleck, M. (2003): Hydraulic performance of artificial reef with rectangular shape. PhD-Thesis (in German): www.biblio.tu-bs.de
- Bleck, M; Oumeraci, H. (2002): Hydraulic performance of artificial reefs: global and local description. Proc. ICCE´02
- Bleck, M.; Oumeraci, H. (2004): Analytical model for wave transmission behind artificial reefs. Proc. ICCE´04

Wave Transformation at a Reef in Waikiki/Hawaii (Gerritsen, 1981)





- Present design: $C_t = H_t / H_i$ (1) and $C^2_t + C^2_r + C^2_d = 1$ (2)

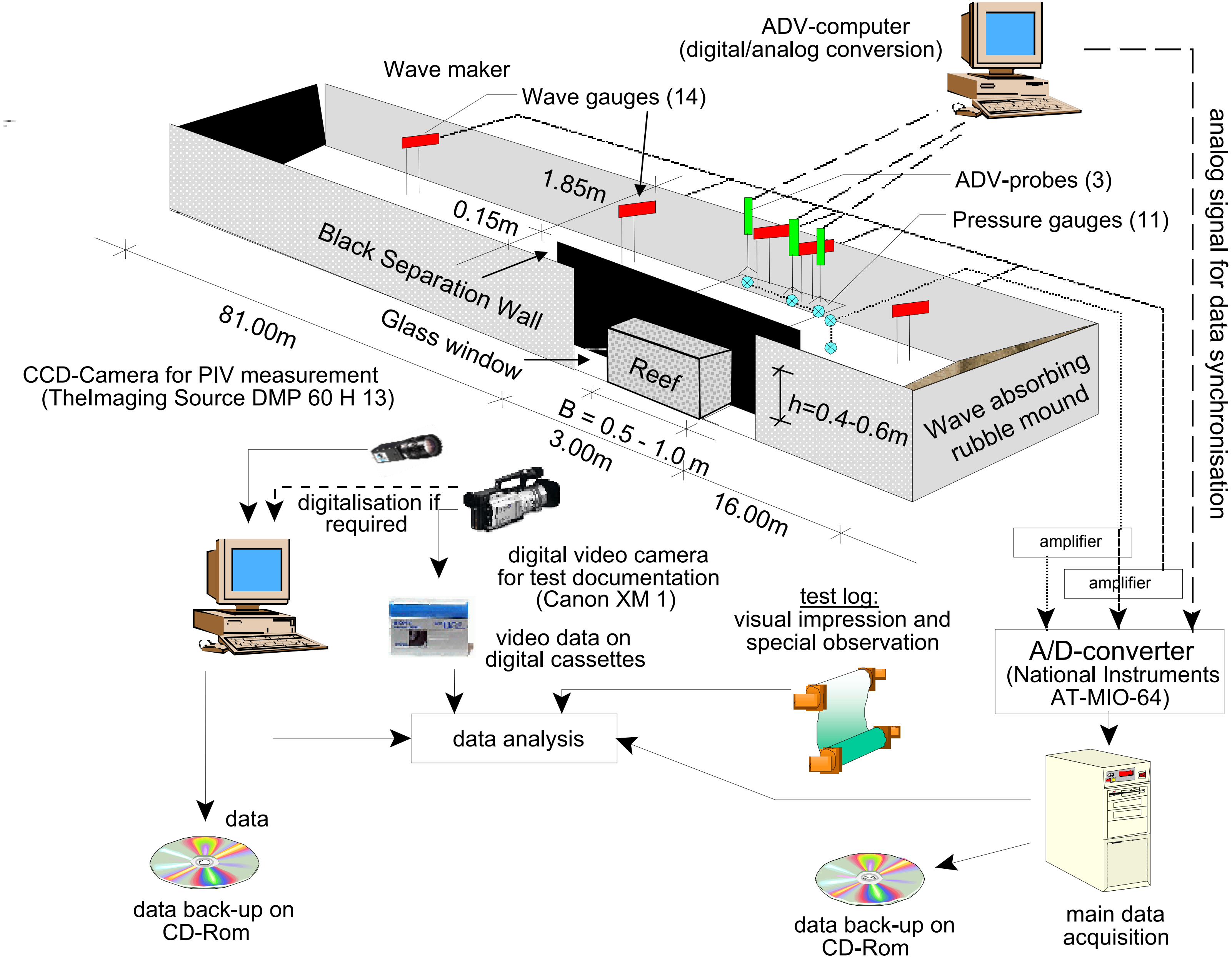
However:

- Shift of wave energy towards higher frequencies behind reef

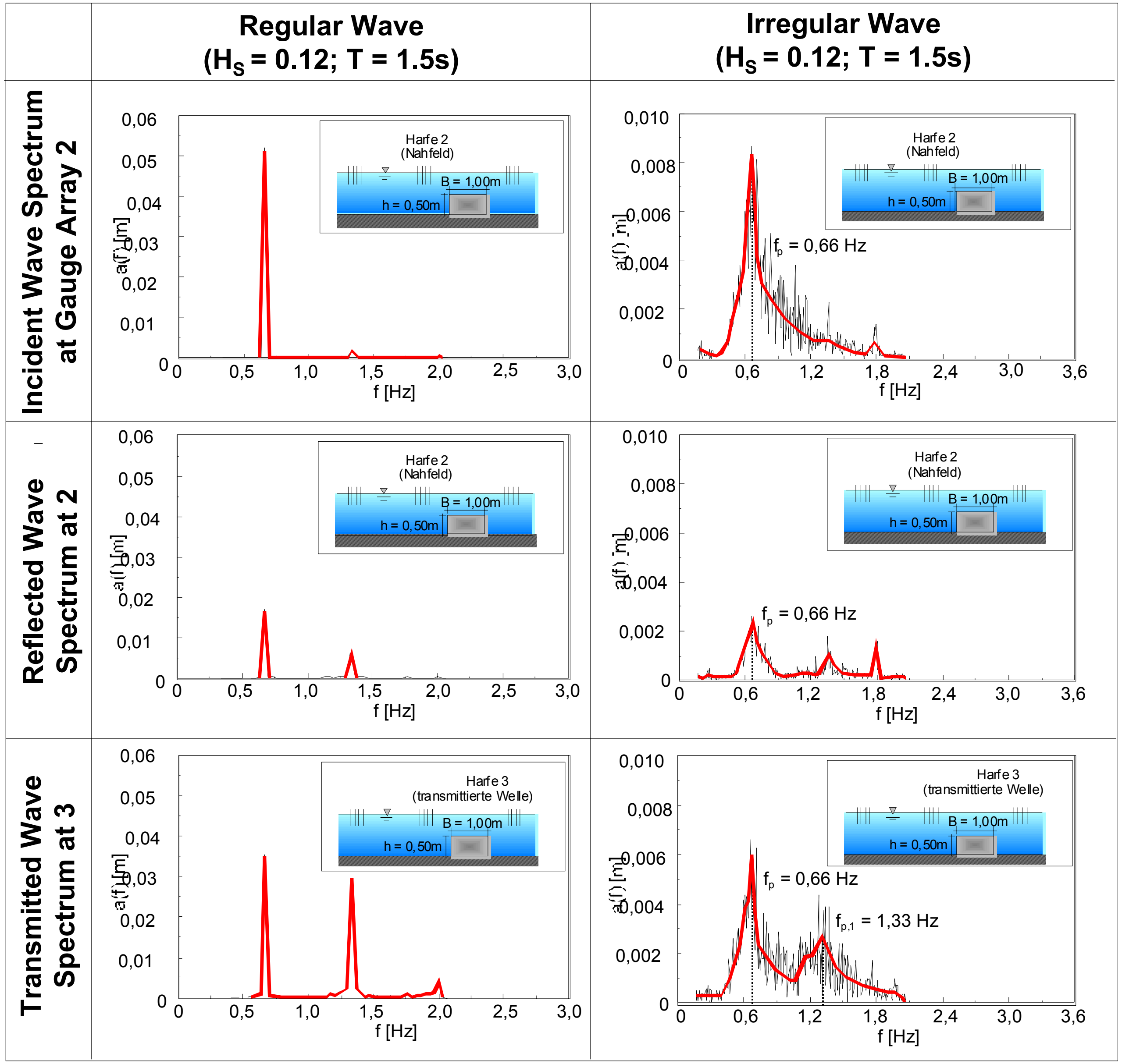
⇓

Equations (1) and (2) not sufficient to describe hydraulic performance

Experimental Set-Up in the Wave Flume of LWI

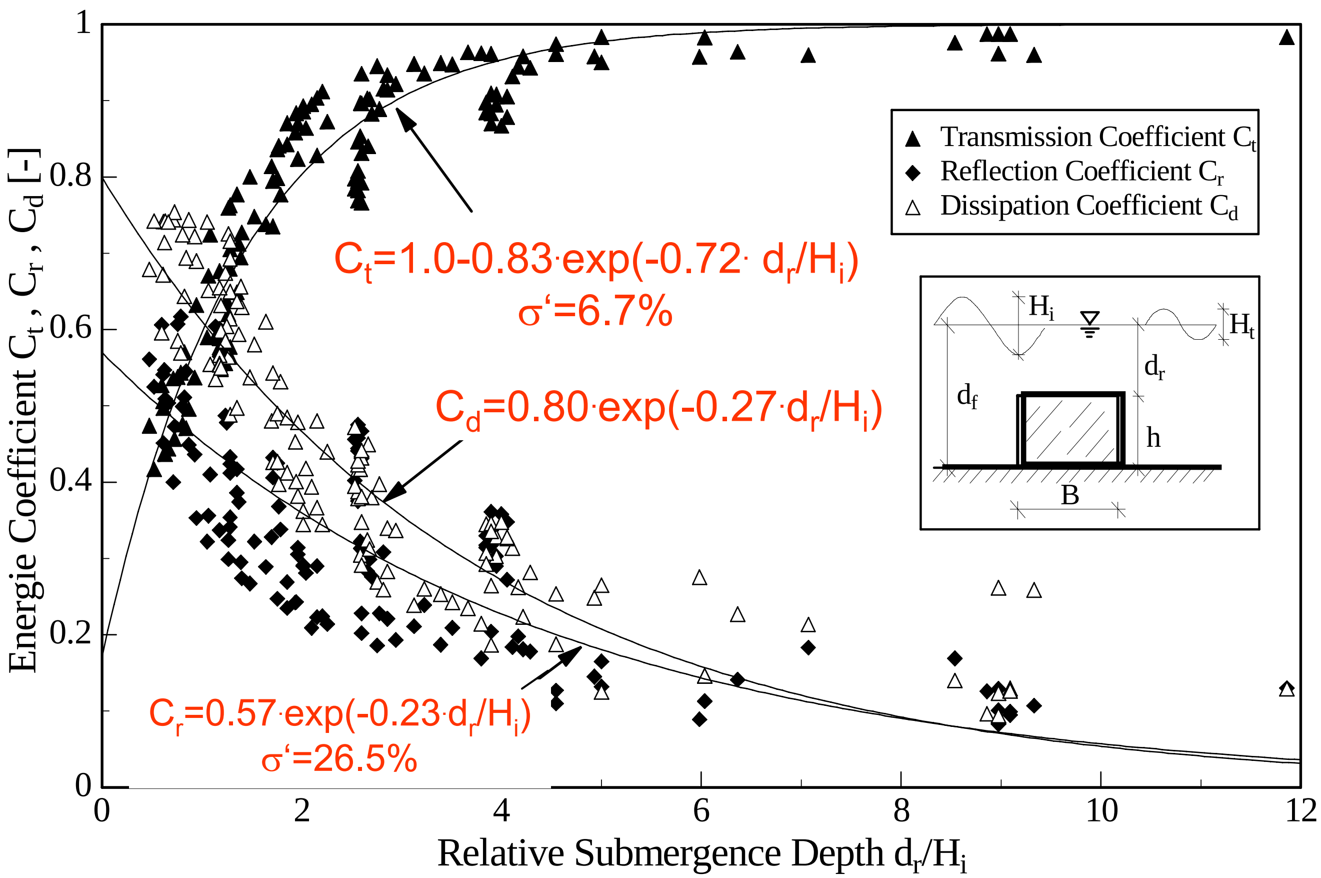


Wave Transformation at a Reef



Effect of Relative Submergence Depth d_r / H_i on Hydraulic Performance

$$C_r^2 + C_d^2 + C_t^2 = 1$$



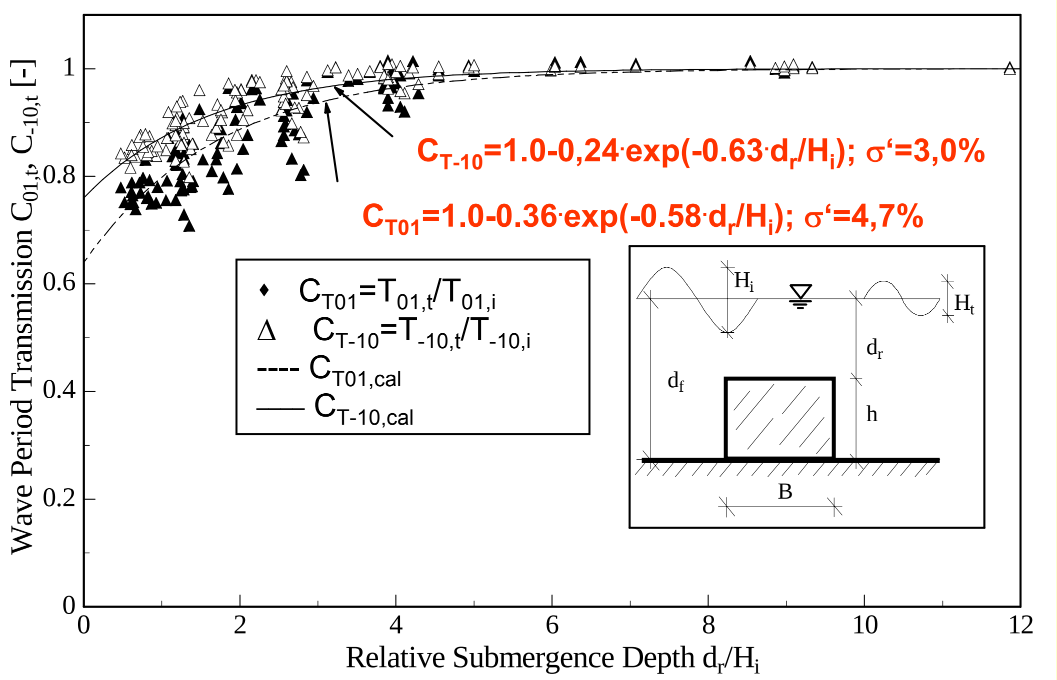
Influencing Parameters on Hydraulic Performance

	Multiple Regression Analysis (d_r/H_i; H_i/L_i; B/L_i)	Simplified (d_r/H_i)
Transmission	$C_t = 0{,}5 + 0{,}5 \cdot \cos\left(0{,}48\left(\frac{B}{L_i}\right)^{0{,}15}\left(\frac{H_i}{L_i}\right)^{-0{,}35}\left(\frac{d_r}{H_i}\right)^{-0{,}7}\right)$ $\sigma'(C_t) = 4{,}6\%$	$C_t = 1{,}0 - 0{,}83 \cdot \exp\left[-0{,}72 \cdot \left(d_r/H_i\right)\right]$ $\sigma'_{Ct} = 6{,}7\%$
Reflection	$C_r = 0{,}5 + 0{,}5 \cdot \cos\left(2{,}66\left(\frac{B}{L_i}\right)^{0{,}01}\left(\frac{H_i}{L_i}\right)^{0{,}125}\left(\frac{d_r}{H_i}\right)^{0{,}2}\right)$ $\sigma'(C_r) = 12{,}3\%$	$C_r = 0{,}57 \cdot \exp\left[-0{,}23 \cdot \left(d_r/H_i\right)\right]$ $\sigma'_{Cr} = 26{,}5\%$
Dissipation	$C_d = 0{,}5 + 0{,}5 \cdot \cos\left(1{,}77\left(\frac{B}{L_i}\right)^{-0{,}1}\left(\frac{H_i}{L_i}\right)^{0{,}14}\left(\frac{d_r}{H_i}\right)^{0{,}45}\right)$ $\sigma'(C_d) = 10{,}5\%$	$C_d = 0{,}80 \cdot \exp\left[-0{,}27 \cdot \left(d_r/H_i\right)\right]$ $\sigma'_{Cd} = 16{,}4\%$

Effect of Relative Submergence Depth d_r / H_i on Periods of Transmitted Waves

$$T_{01} = \frac{m_0}{m_1} = \frac{\int S(f)df}{\int S(f)fdf} \qquad T_{-10} = \frac{m_{-1}}{m_0} = \frac{\int S(f)f^{-1}df}{\int S(f)df}$$

$$C_{T01} = \frac{(T_{01})_t}{(T_{01})_i}; \qquad C_{T-10} = \frac{(T_{-10})_t}{(T_{-10})_i}$$



Description of Transmitted Wave Spectrum by Three Spectral Parameters

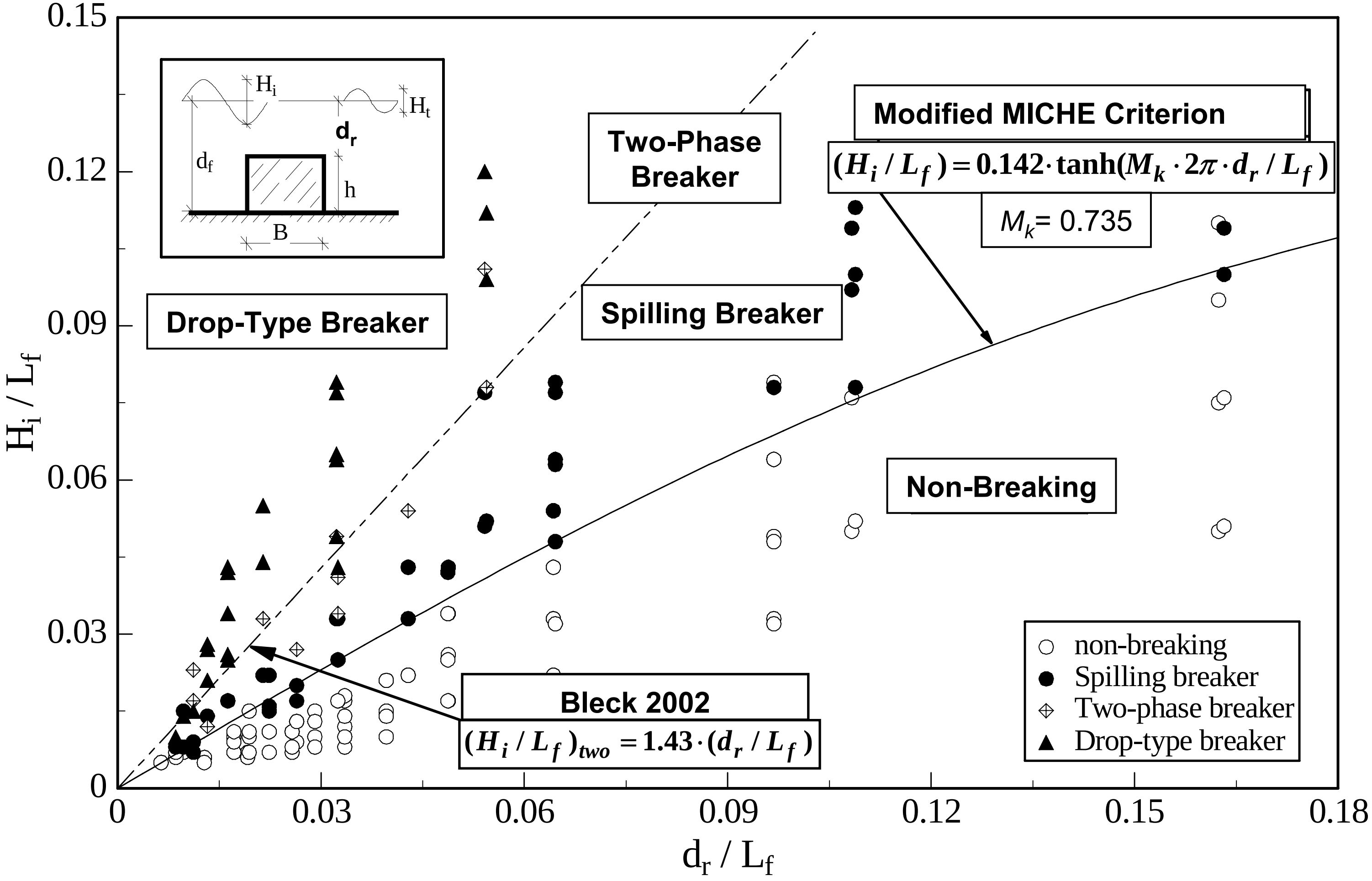
$$\mathbf{C_{m_0}} = \frac{\mathbf{(m_0)_t}}{\mathbf{(m_0)_i}} \qquad \left(= \mathbf{C_t}^2 = \frac{(H_{m_0})_t^2}{(H_{m_0})_i^2} \right) \qquad \text{with} \qquad \mathbf{C_t} = 1.0 - 0.83 \cdot \exp(-0.72 \cdot d_r / H_i)$$

$$\mathbf{C_{m_1}} = \frac{\mathbf{(m_1)_t}}{\mathbf{(m_1)_i}} \qquad \left(= \mathbf{C_{m_0}} / C_{T_{01}} \right) \qquad \text{with} \qquad \mathbf{C_{T_{01}}} = \frac{(T_{01})_t}{(T_{01})_i} = 1 - 0.36 \cdot \exp(-0.58 \cdot d_r / H_i)$$

$$\mathbf{C_{m_{-1}}} = \frac{\mathbf{(m_{-1})_t}}{\mathbf{(m_{-1})_i}} \qquad \left(= \mathbf{C_{m_0}} \cdot C_{T_{-10}} \right) \qquad \text{with} \qquad \mathbf{C_{T_{-10}}} = \frac{(T_{-10})_t}{(T_{-10})_i} = 1 - 0.24 \cdot \exp(-0.63 \cdot d_r / H_i)$$

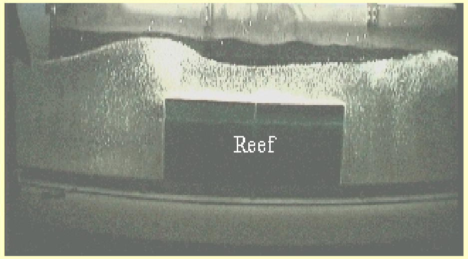
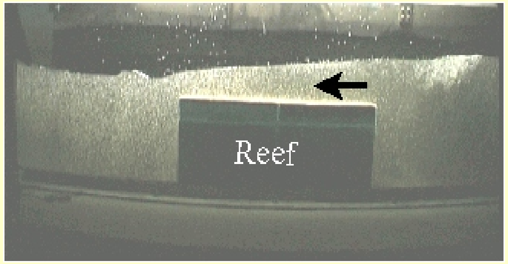
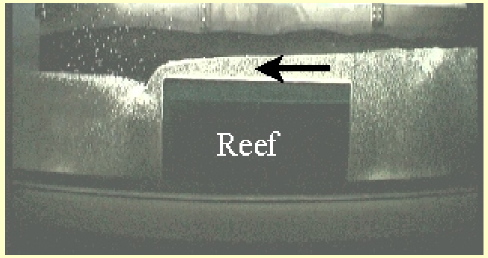
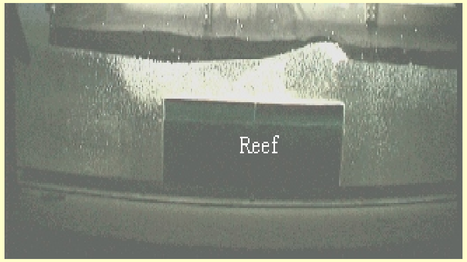
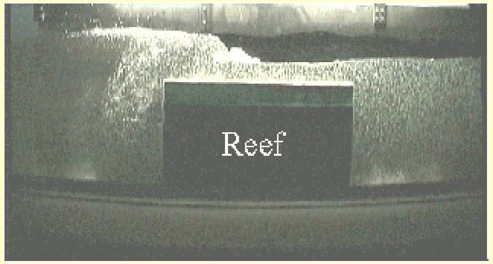
where $\mathbf{m_n} = \int S(f) f^n df;$ $\quad \mathbf{T_{01}} = \frac{m_0}{m_1}$ and $\mathbf{T_{-10}} = \frac{m_{-1}}{m_0}$

Breaking Criterion and Breaker Types



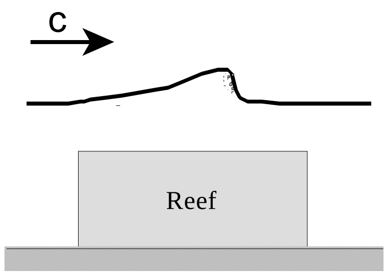
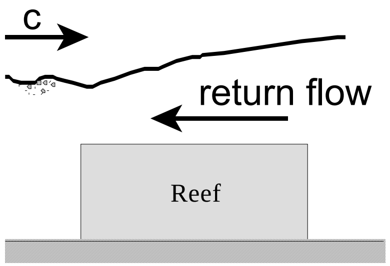
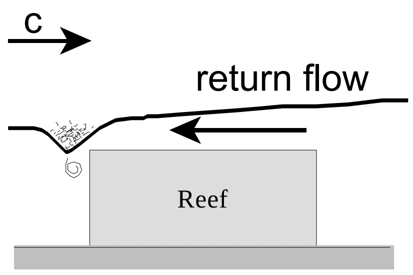
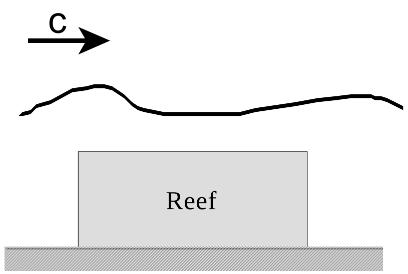
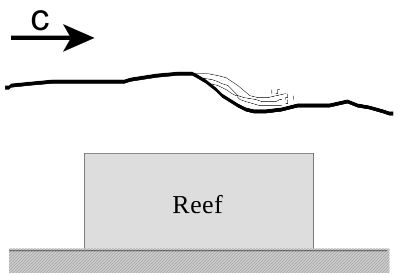
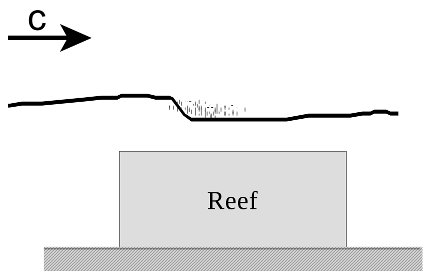
Breaker Types on Reefs: Energy Dissipation

$$C_d = \sqrt{E_D / E_i}$$ with E_D, E_i = dissipated and incident wave energy.

Spilling breaker	Two- Step breaker	Drop- type breaker
		
		
$C_d = 0.4 \div 0.60$ $(\bar{C}_d \approx 0.55)^*$	$C_d = 0.35 \div 0.85$ $(\bar{C}_d \approx 0.54)$	$C_d = 0.4 \div 0.90$ $(\bar{C}_d \approx 0.68)$

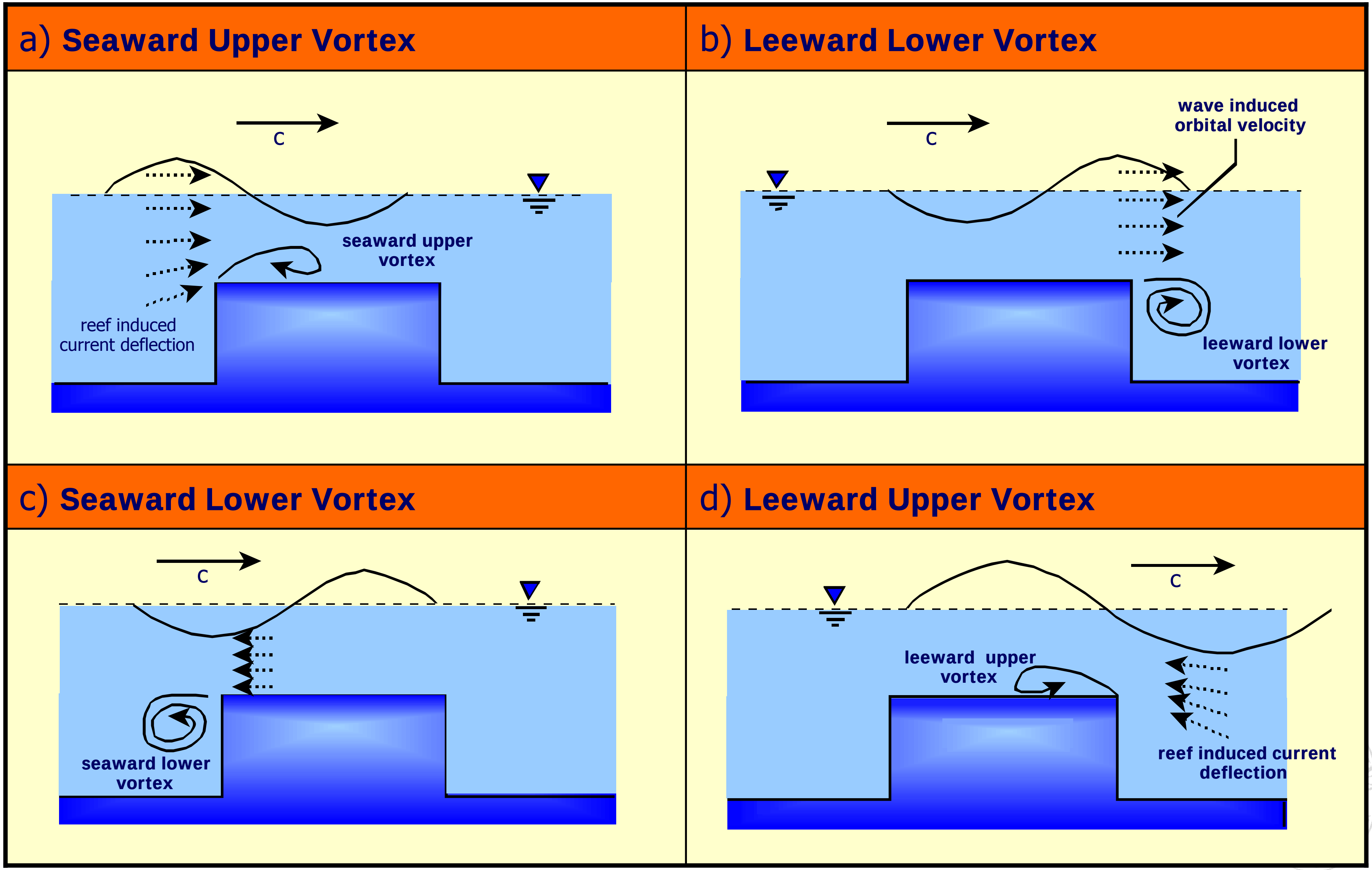
* Non-Breaking waves: $\bar{C}_d = 0.33$

Breaker Types on Reefs: Energy Dissipation

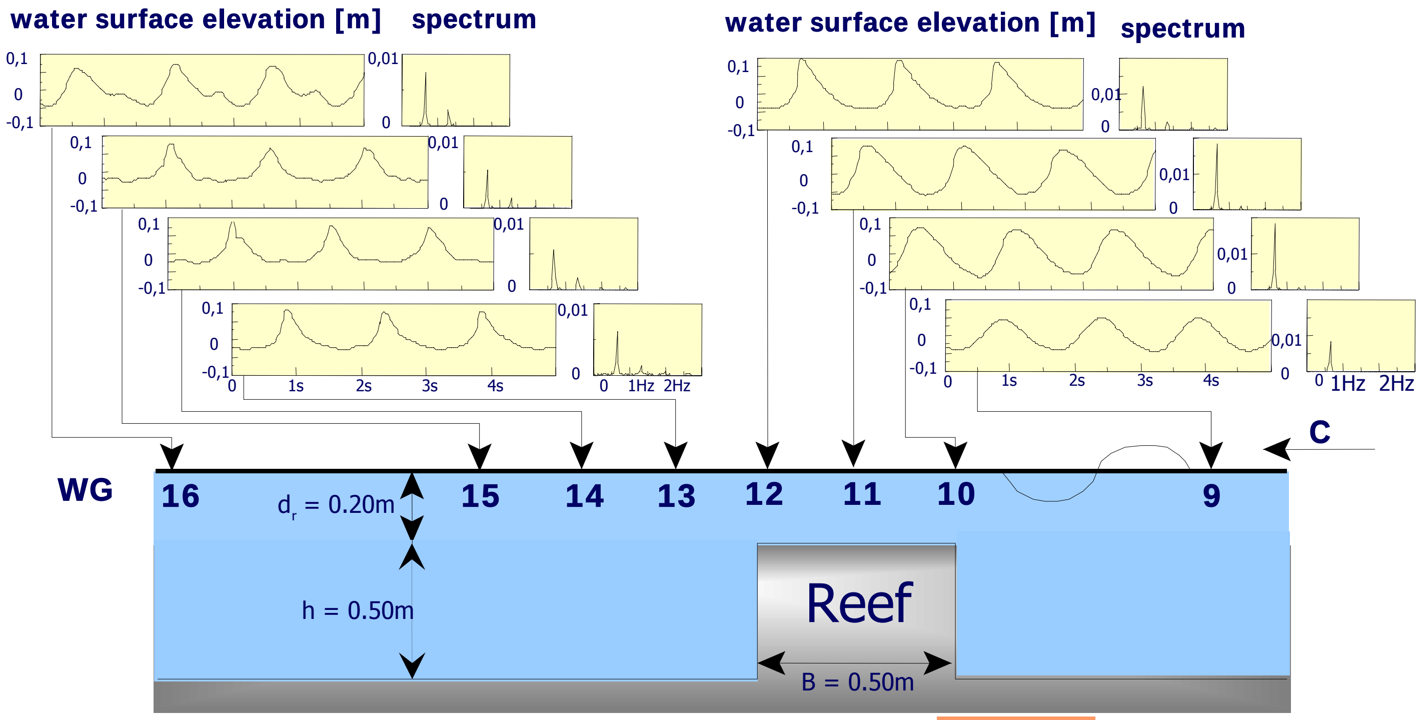
Spilling breaker	Two-Step breaker	Drop-type breaker
		
		
$C_d = 0.4 \div 0.6$ $(\overline{C}_d \approx 0.55)$*	$C_d = 0.35 \div 0.85$ $(\overline{C}_d \approx 0.54)$	$C_d = 0.4 \div 0.90$ $(\overline{C}_d \approx 0.68)$

* Non-Breaking waves: $\overline{C}_d = 0.33$

Vortex Losses

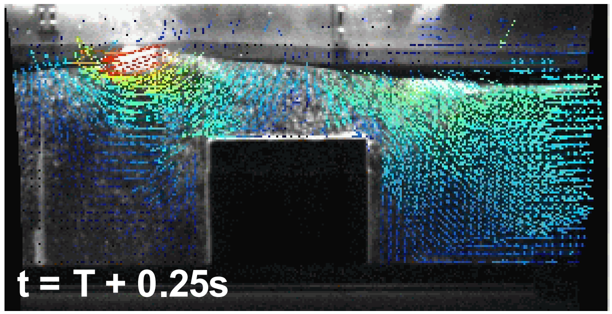


Non-Linear Effects with Wind Waves for B/L = 0.16



$H_i/L_i = 0.04 \Rightarrow d_r/H_i = 1.6$; **$B/L_i = 0.16$**

c



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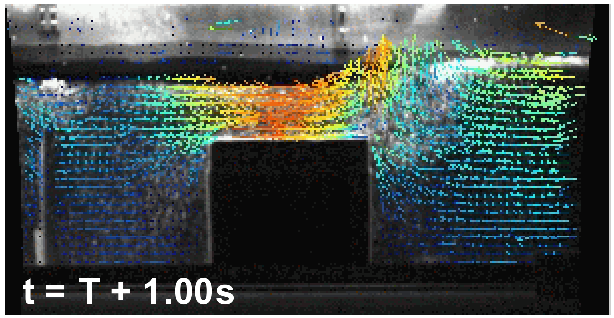
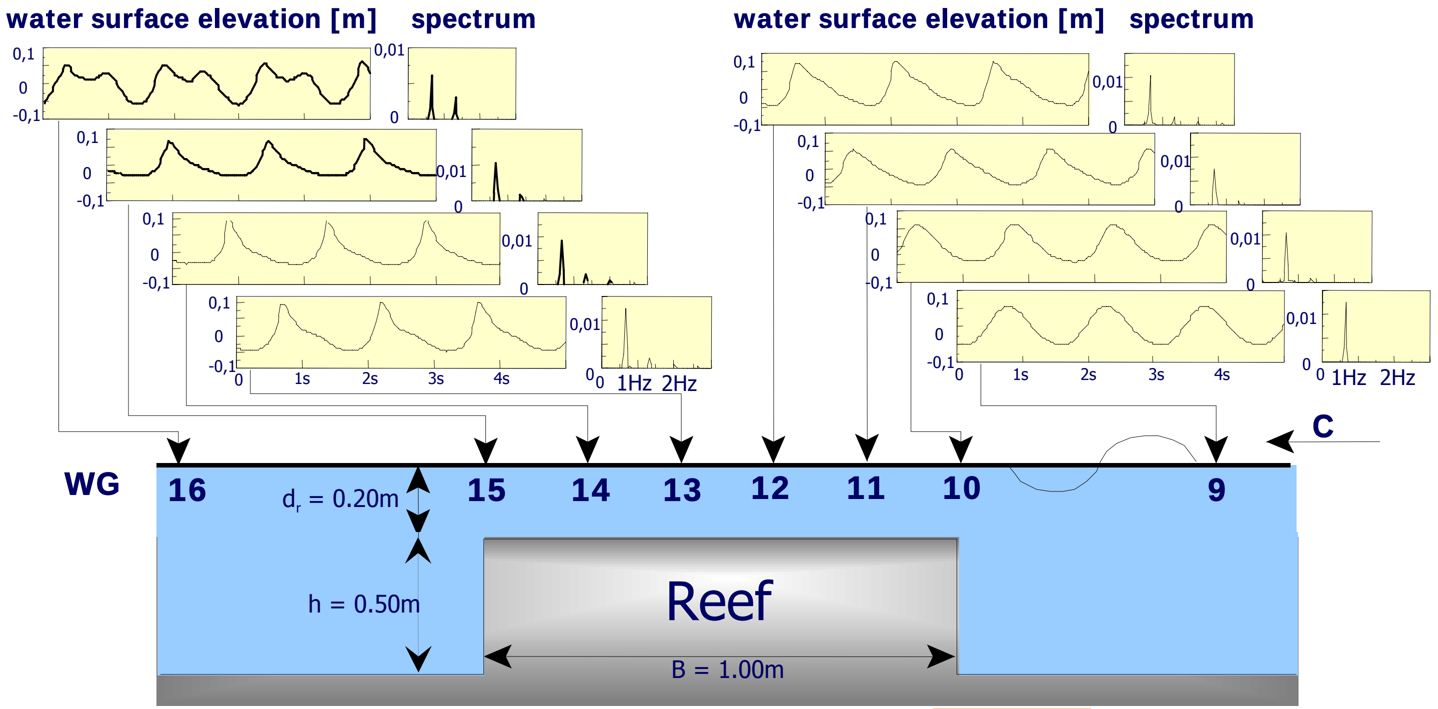
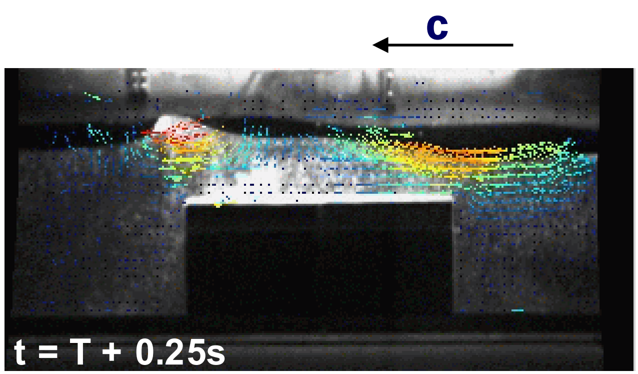
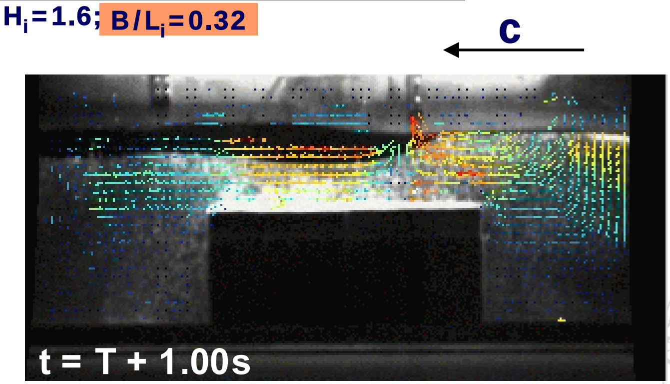


Non-Linear Effects with Wind Waves for B/L = 0.32

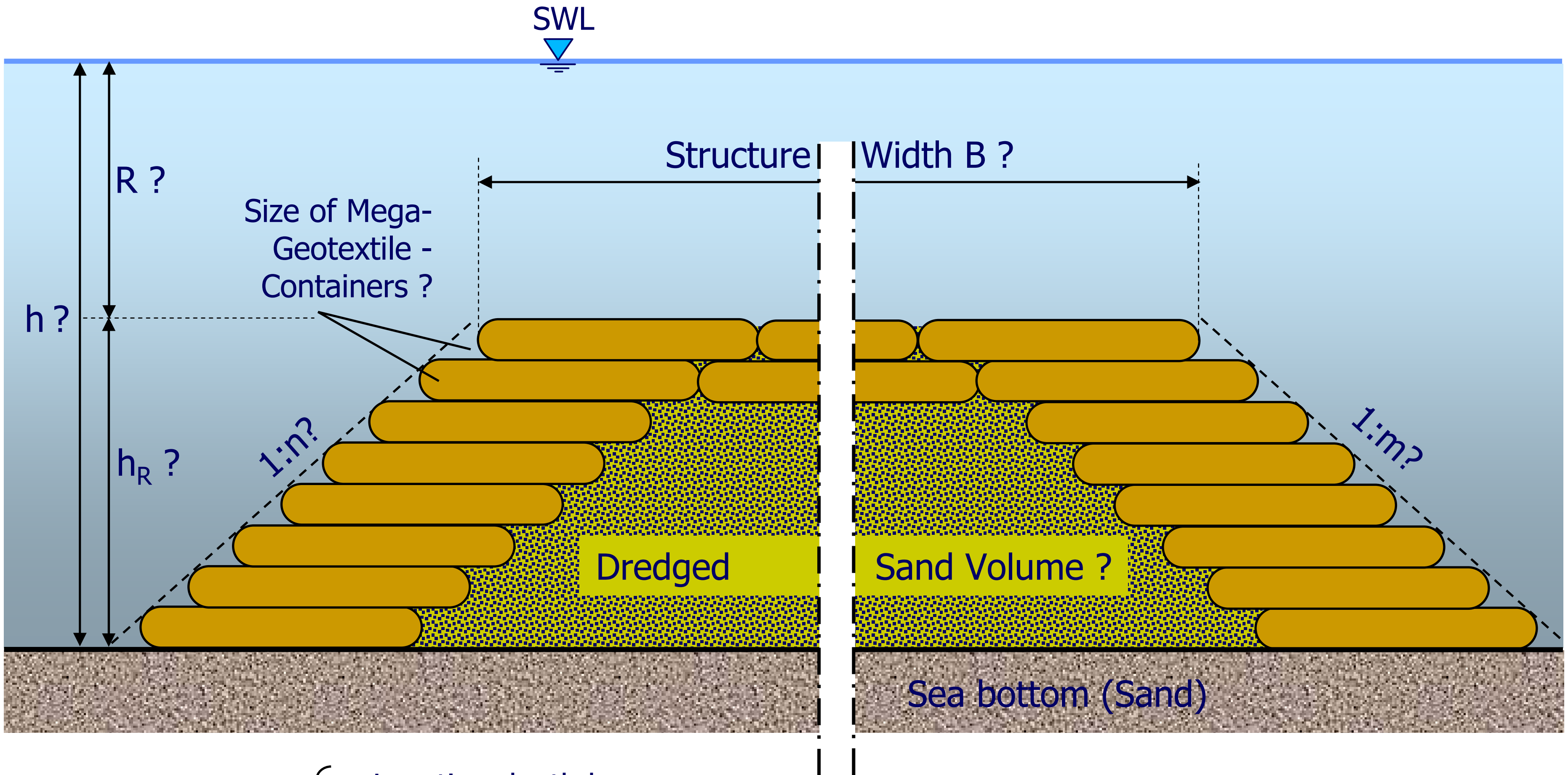


$H_i/L_i = 0.04 \Rightarrow d_r/H_i = 1.6$; **$B/L_i = 0.32$**





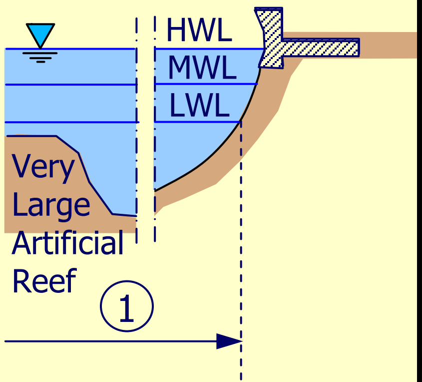
Possible Application for Tsunami (Feasibility Study in Progress)



Reef Parameters
- Location depth h
- Structure width B and slope steepness 1:n and 1:m
- Reef height h_R and submergence depth R
- Size (volume, weight) of geotextile containers

must be determined as a function of target incident Tsunami wave parameters and target level of tsunami attenuation (transmitted wave parameters). The latter will depend on the nature of the next defence line(s) and the vulnerability of the flood prone area.

Example of Mega Geocontainers used for a surfing Reef in Australia



(1b) Mega-Geo-containers

Feasibility for the full range of wave periods (5 - 60 minutes) of tsunamis has first to be first checked.

Hydraulic Performance of Wave Absorbers

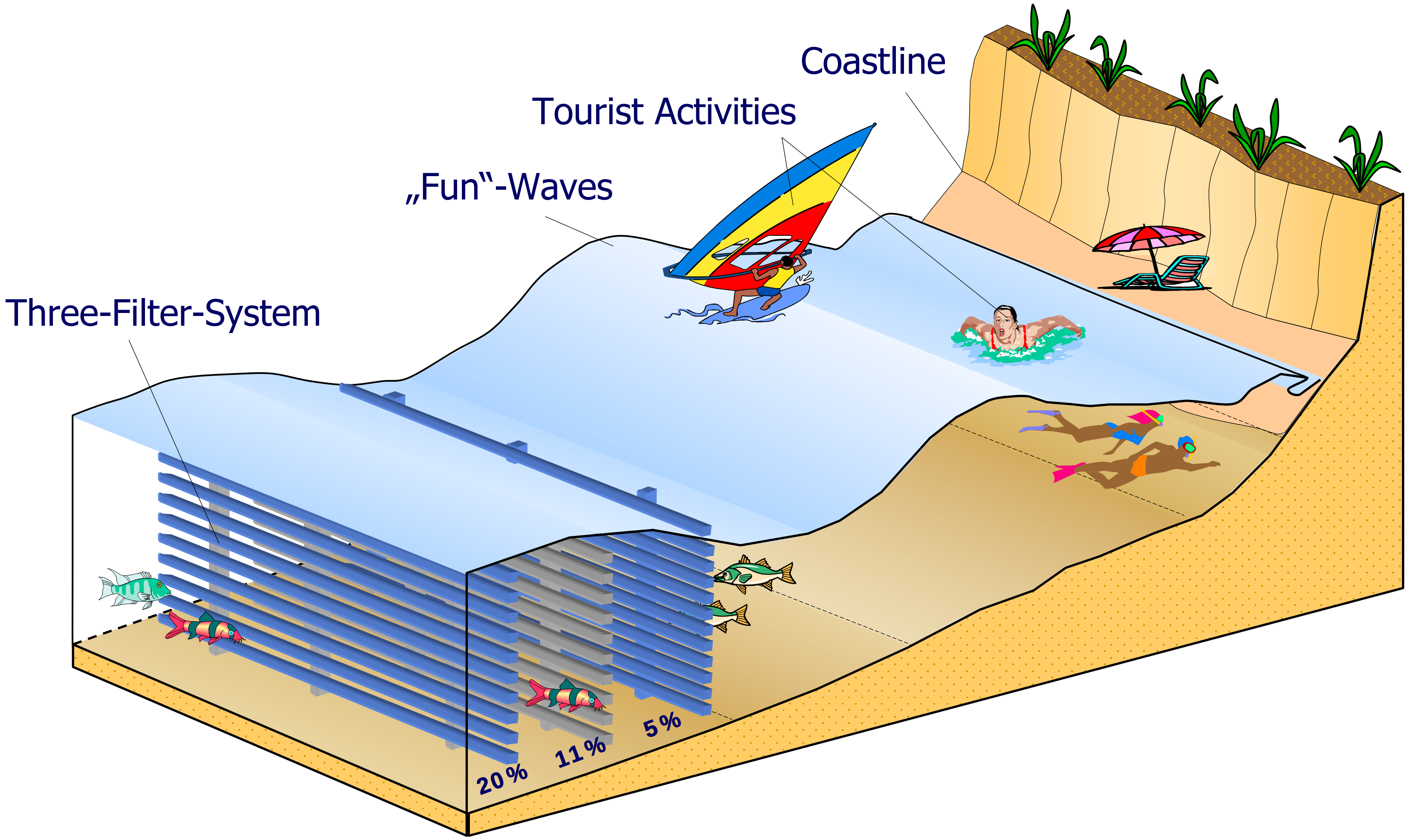
Submerged Wave Absorbers as Artificial Reefs for Coastal Protection

Experimental and Theoretical Investigations for Storm Waves

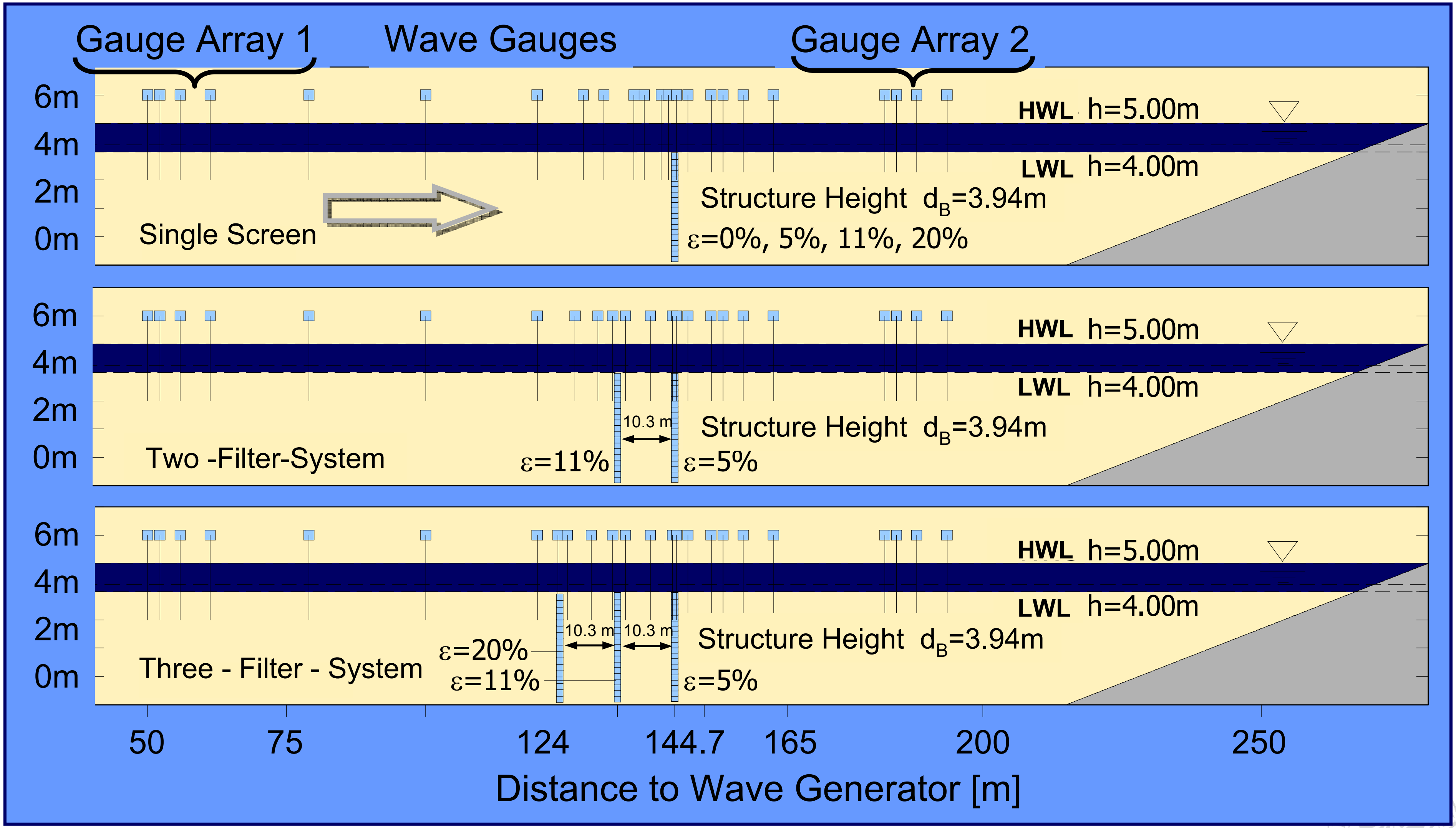
References:

- Oumeraci, H.; Clauss, G.F.; Habel R. Koether, G. (2001): Unterwasserfiltersysteme zur Wellendämpfung. Abschlussbericht zum BMBF-Vorhaben „Unterwasserfiltersysteme zur Wellendämpfung“. Final Research Report, (in German)
- Koether, G. (2002): Hydraulische Wirksamkeit und Wellenbelastung getauchter Eiinzelfilter und Unterwasserfiltersysteme für den Küstenschutz, PhD-Thesis, TU Braunschweig, Leichtweiss-Institut für Wasserbau, (in German)
- Oumeraci, H.; Koether, G. (2004): Innovative Reef for Coastal Protection Part I: Hydraulic Performance, Proc. 2nd joint German-Chinese Symposium on Coastal and Ocean Engineering.
- Oumeraci, H.; Koether, G. (2007): Innovative Reef for Coastal Protection – Part II Wave Loading (in preperation)

Submerged Wave Absorbers for Beach Protection



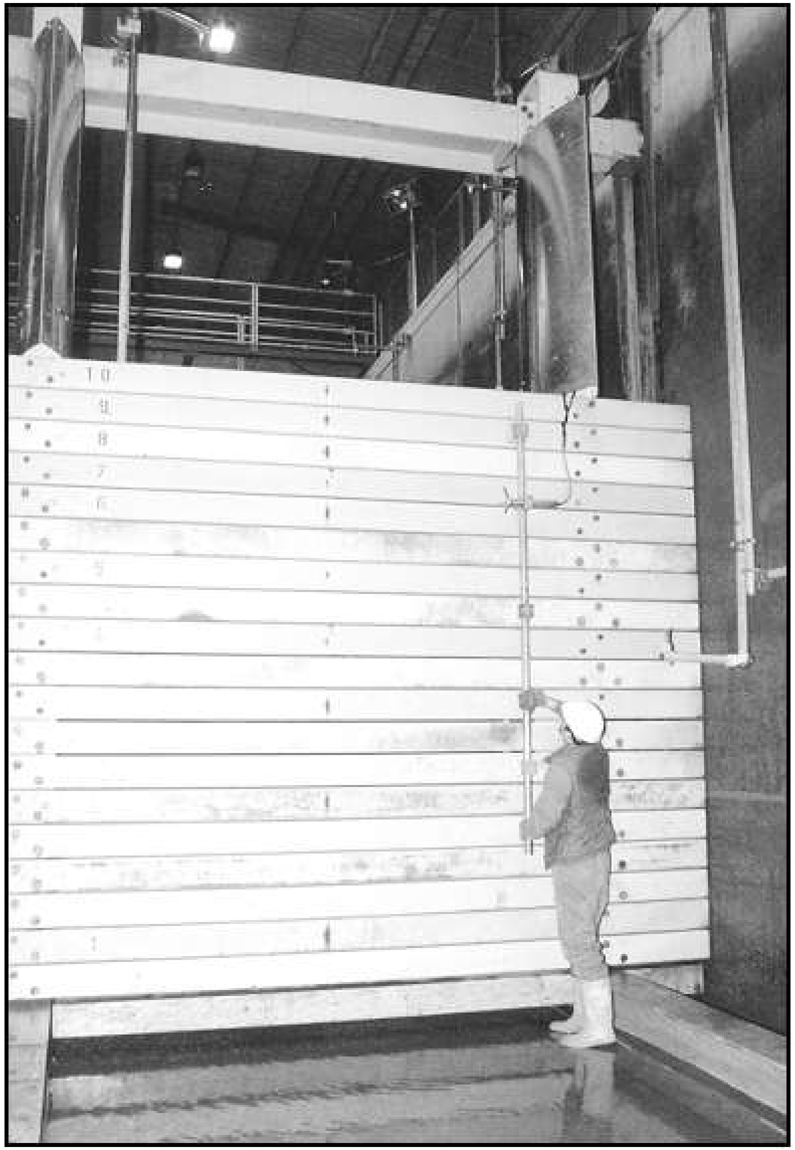
Experimental Set-Up in Large Wave Flume Hannover (GWK)

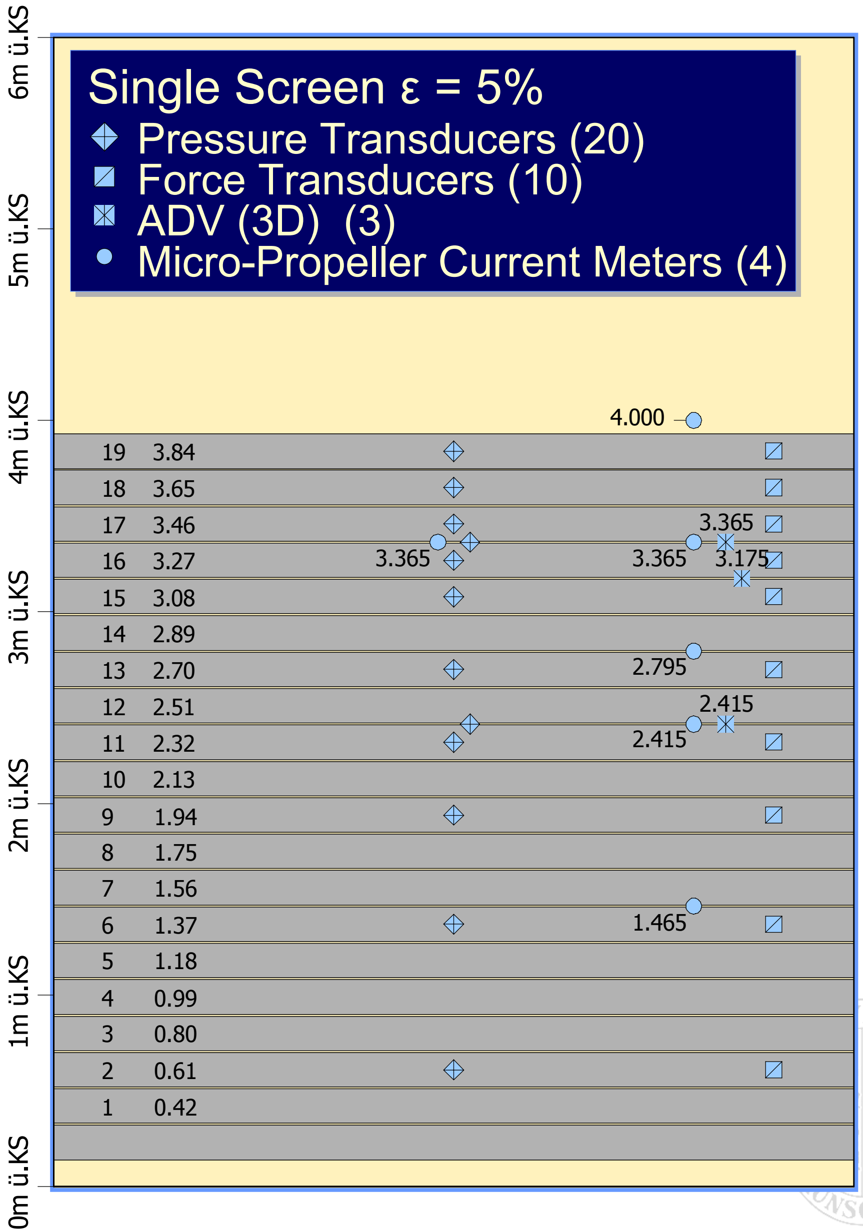


⇒ Wave Heights: H_s = 0.5m - 1.5m

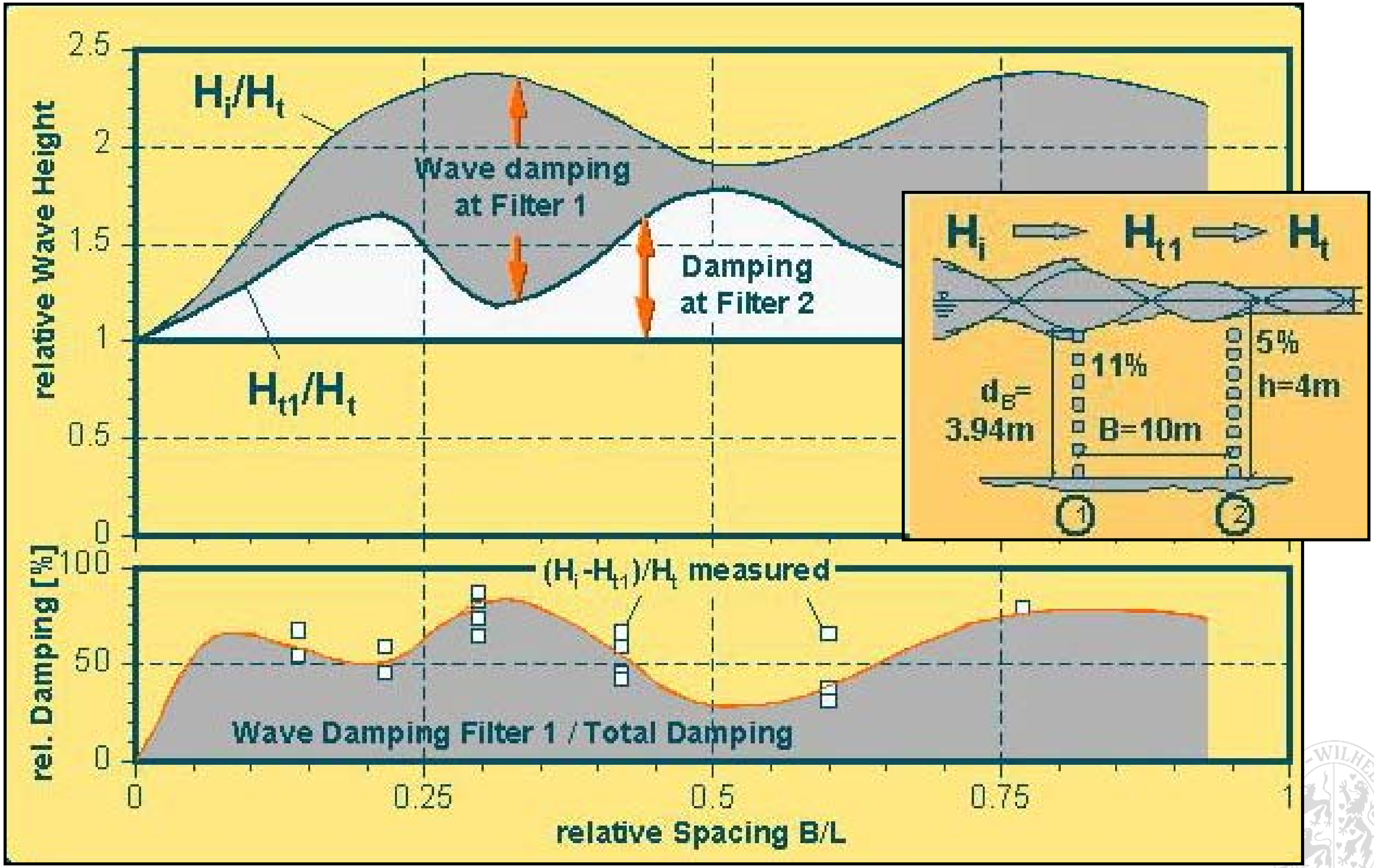
⇒ Wave Periods: T_p = 3s - 12s

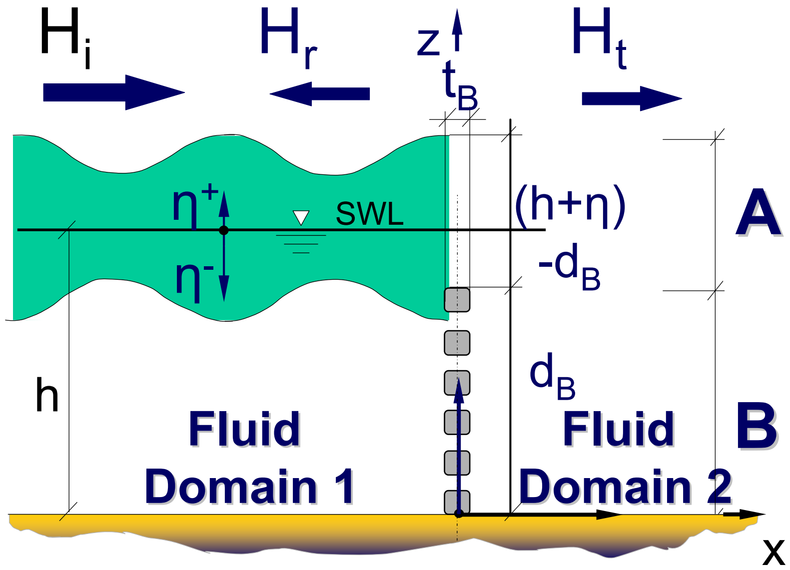
Measuring Devices at the Wall





Contribution of Each Filter to Total Wave Damping





S= Structure Parameter including drag, inertia and vortex losses

⇒ Velocity Potential

$$\phi_1 = \phi_i - \sum_{m=0}^{\infty} a_m \cos(\mu_m z)\exp(\mu_m x)$$

$$\phi_2 = \phi_i + \sum_{m=0}^{\infty} a_m \cos(\mu_m z)\exp(-\mu_m x)$$

⇒ Matching Conditions at Wall

* Upper Zone A (Velocity and Pressure)

$$\frac{\partial \phi_1}{\partial x} = \frac{\partial \phi_2}{\partial x} \quad \text{and} \quad \phi_1 = \phi_2$$

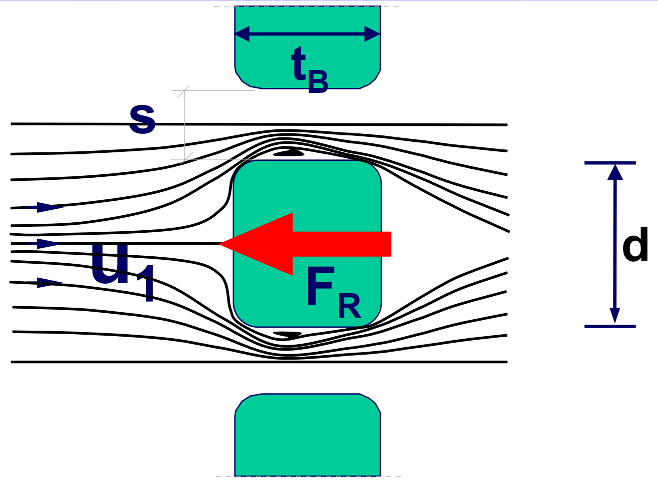
* Lower Zone B (Velocity $\propto$ Pressure diff.)

$$\frac{\partial \phi_1}{\partial x} = \frac{\partial \phi_2}{\partial x} = -i\,S(\phi_2 - \phi_1)$$

New Structure Parameter S for Submerged Filter

Modified MORISON-Equation

$$F_R = C_D^* \cdot \frac{\rho_w}{2} \cdot d \cdot |u_1| u_1 + C_I^* \cdot \rho_w \cdot t_B \cdot d \cdot \frac{\partial u_1}{\partial t}$$



Drag Component
Force Measurement at $\partial u_1/\partial t = 0$, $u_1 \neq 0$,

Modified Drag Coeff. c_D^* → Linearisation → $f_D = f_D(C_D^*)$

Inertia Component
Force Measurement at $u_1 = 0$, $\partial u_1/\partial t \neq 0$

Modified Inertia Coeff. C_I^* → $f_I = C_I^*$

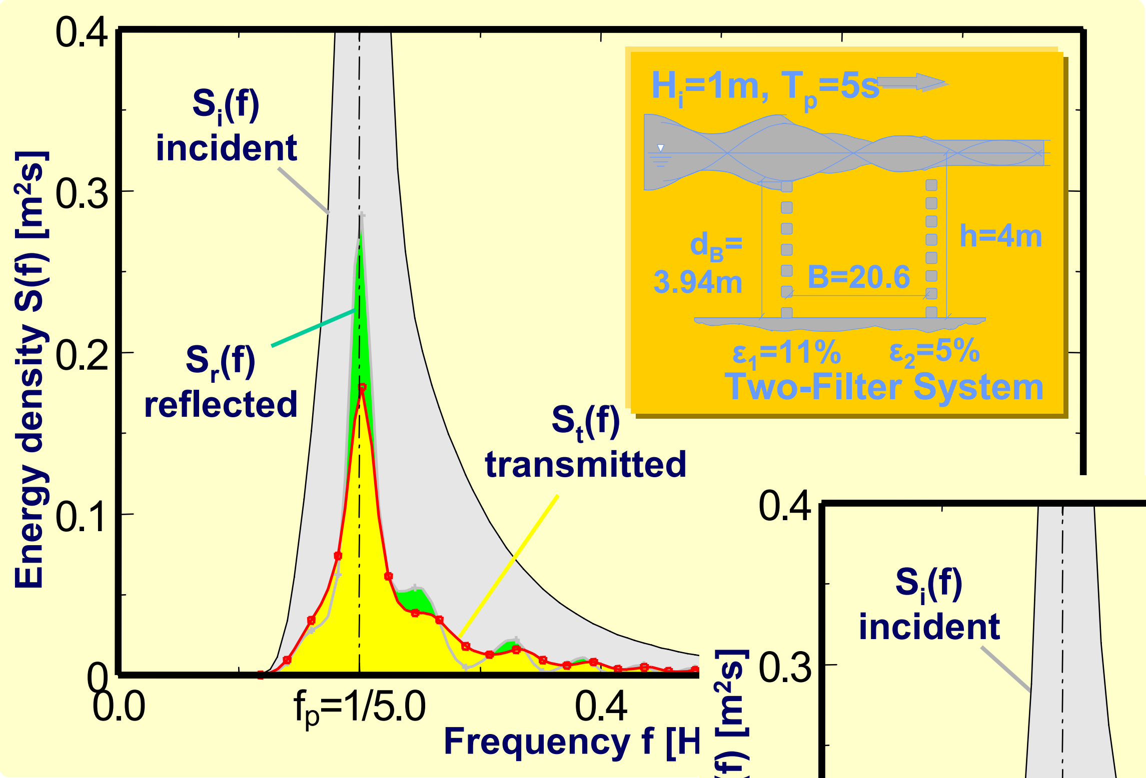
Vortex Loss
C_v by Stiassnie et al. (1984)

Modified Loss Coeff. $C_v^* = C_v(1-\varepsilon^{1/2})$ and Linearisation → $f_v = f_v(C_v^*)$

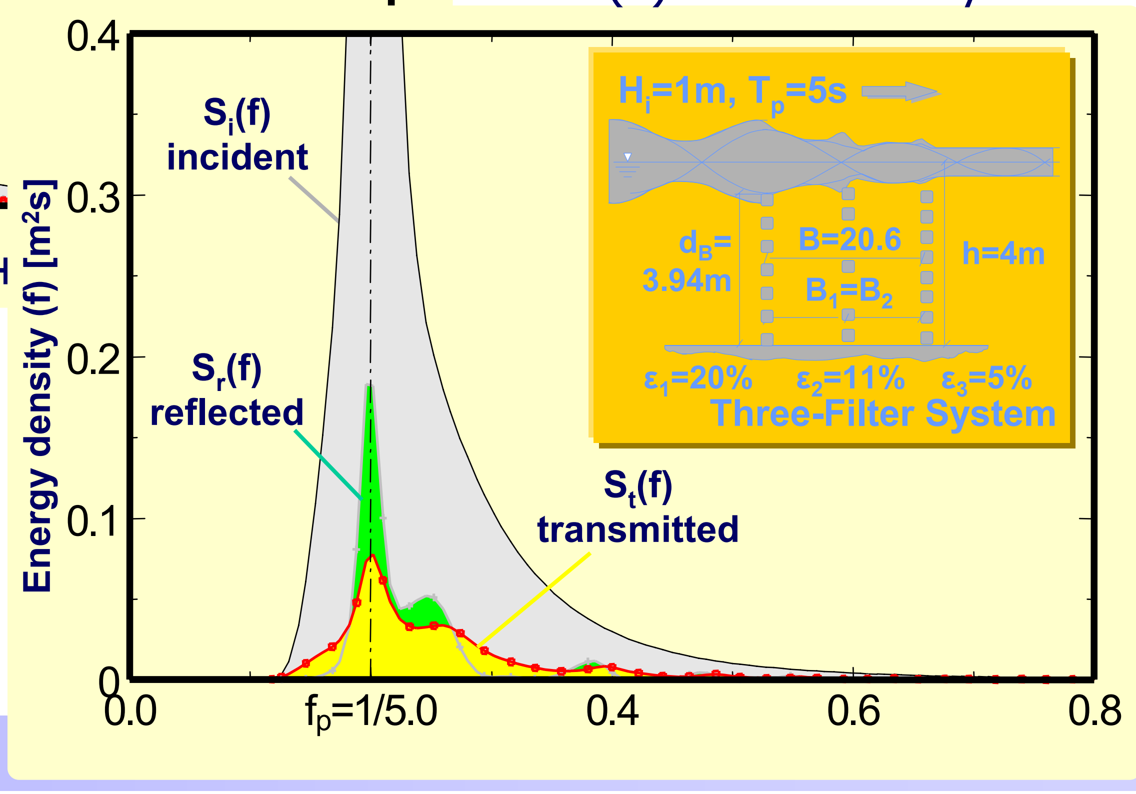
$$S = \frac{1}{(f_D + f_V) - if_I}$$

Calculated Reflected and Transmitted Wave Spectra by Reef

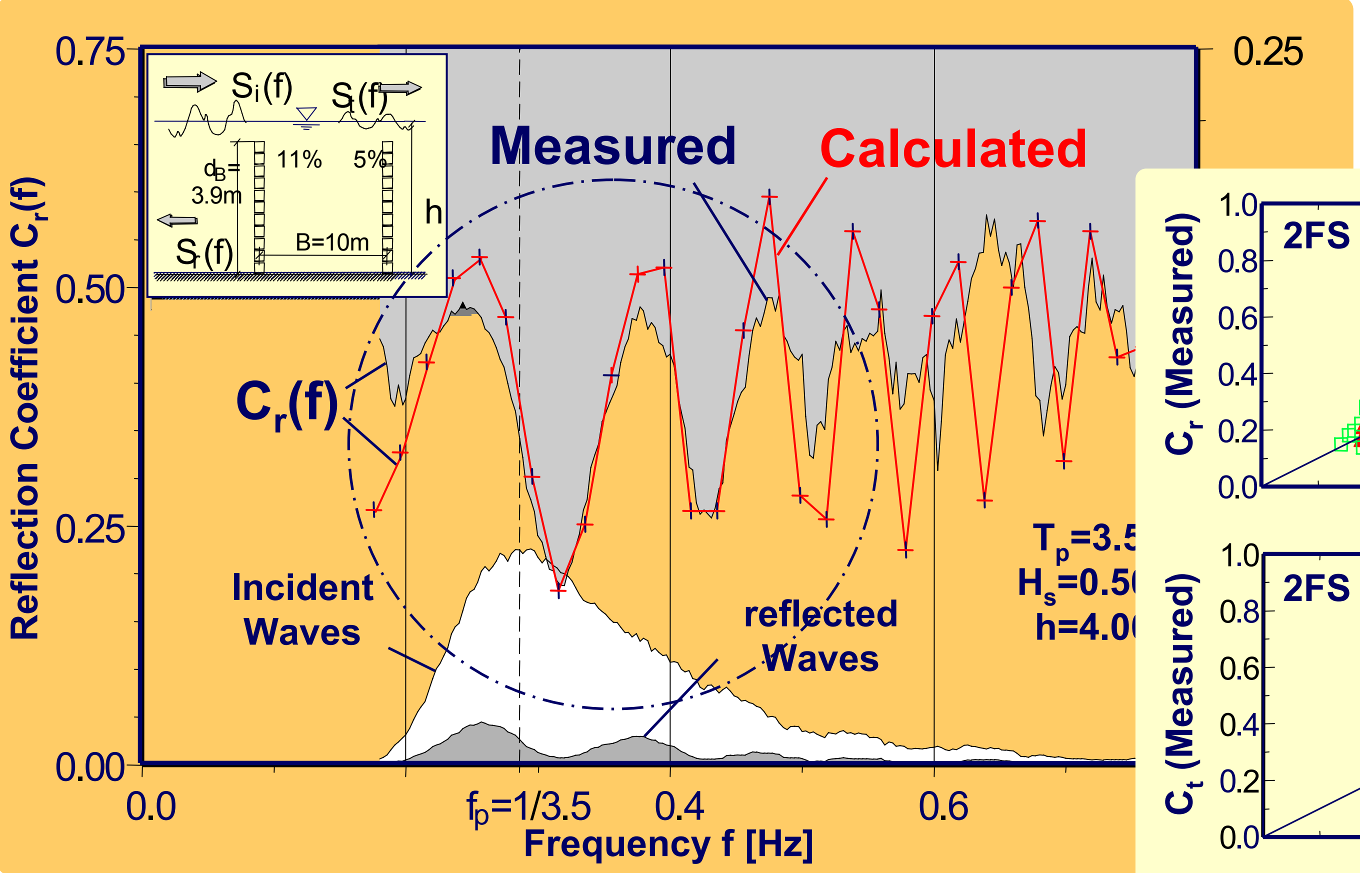
(a) Two filter System

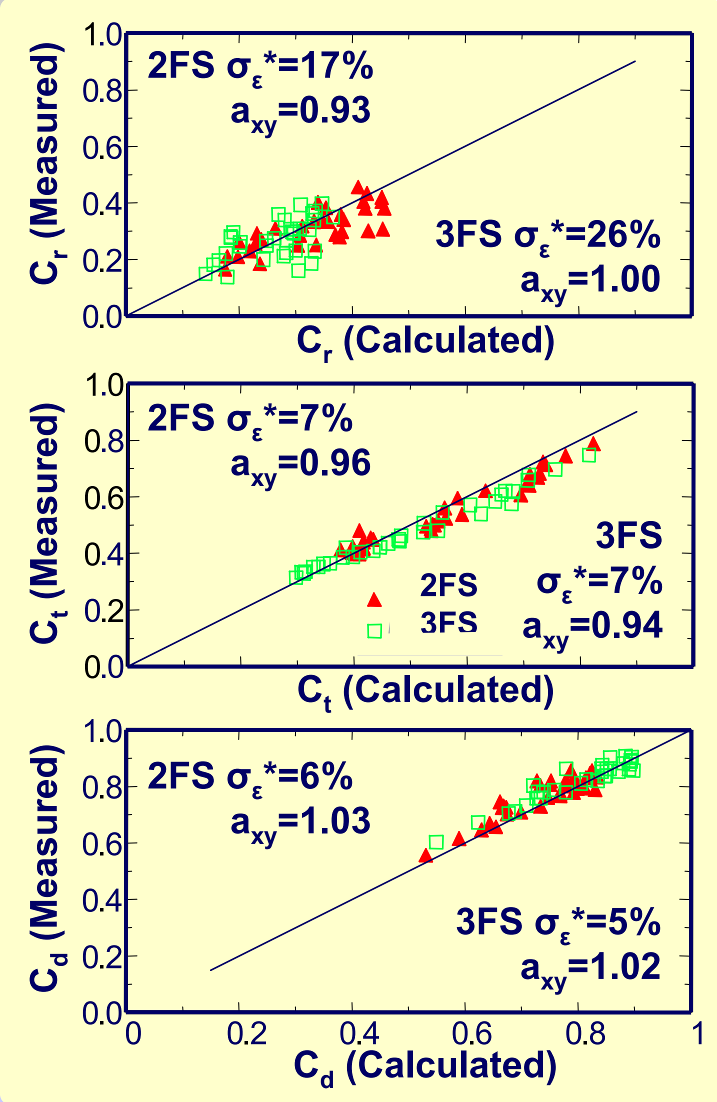


(b) Three filter System



Model Validation for Irregular Waves

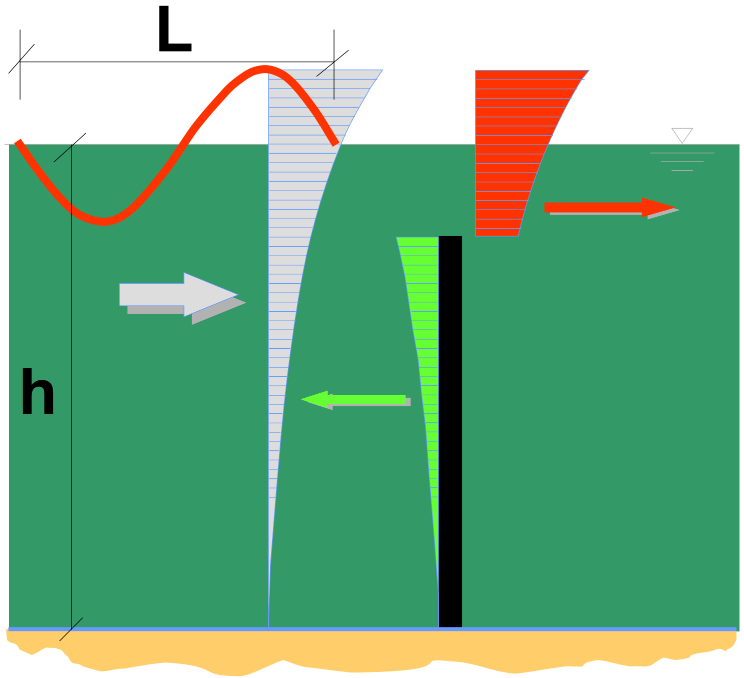




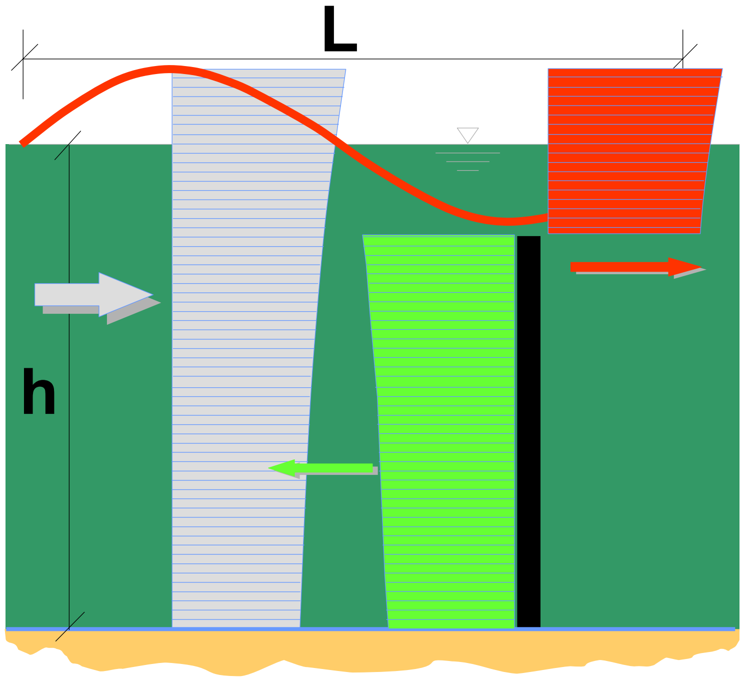
Differences between Short and Longer Waves

Wave Energy Distribution over the Entire Water column

Shorter Period Waves (larger h/L)
(representative for storm waves)

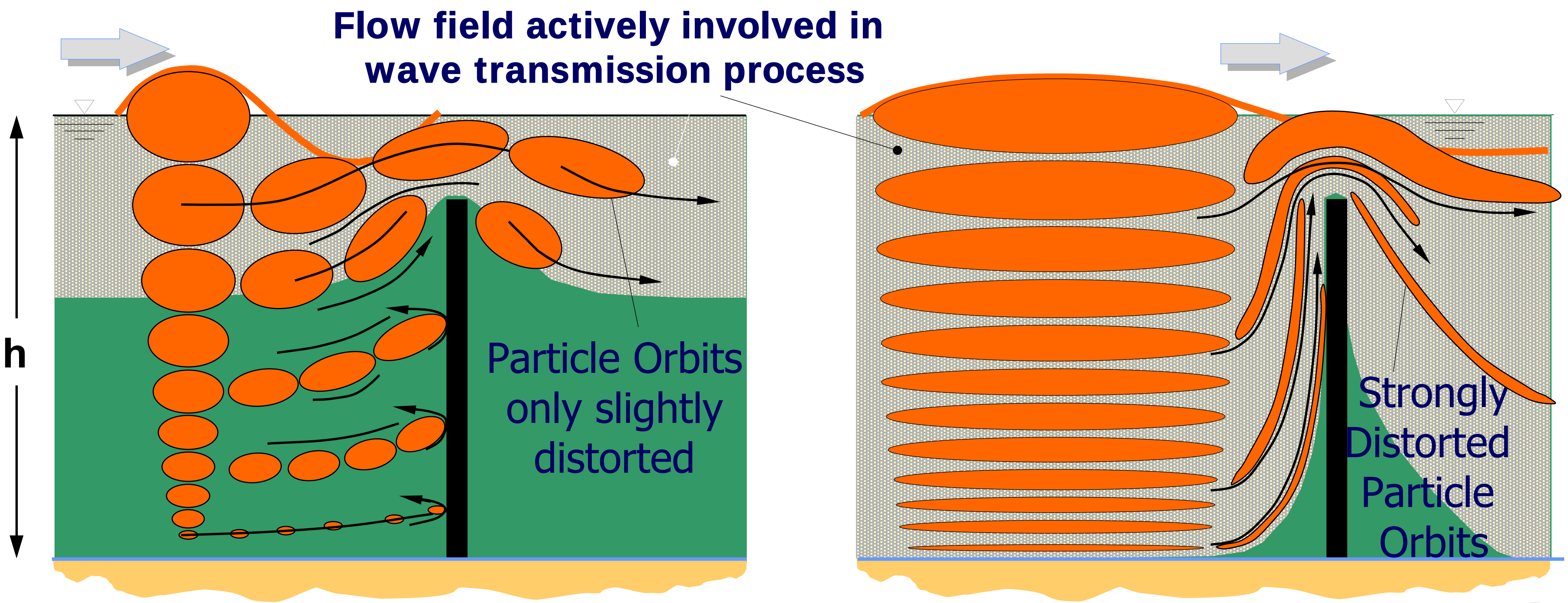


Longer Period Waves (smaller h/L)
(representative for tsunami)



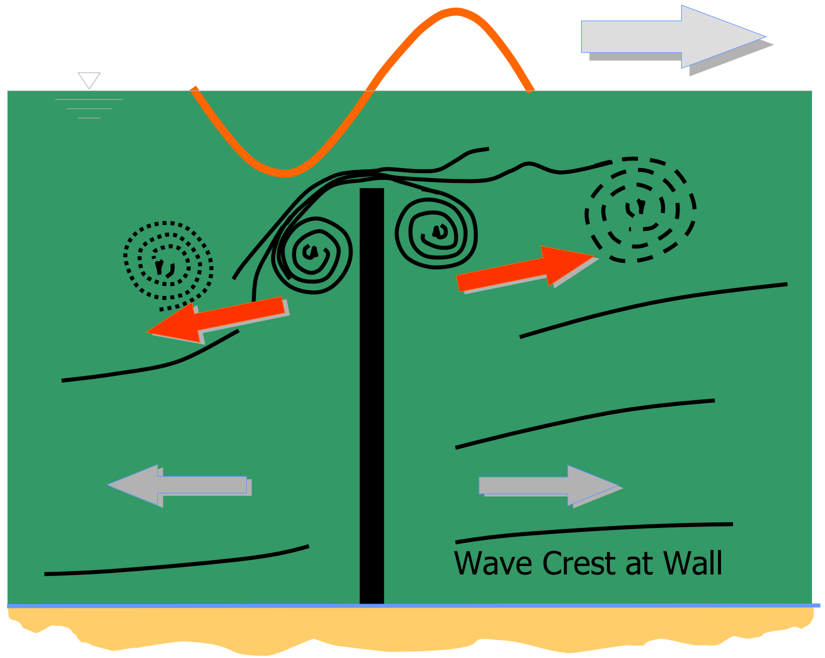
Orbital Flow characteristics

Shorter Period Waves (larger h/L) | **Longer Period Waves (smaller h/L)**

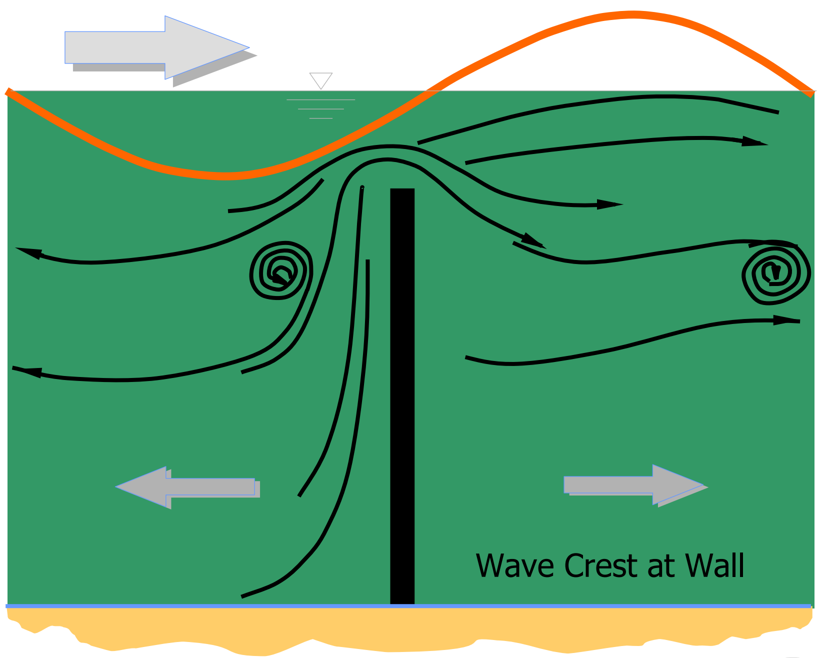


Energy Loss due to Flow Separation and Vorticies at Wall Crest

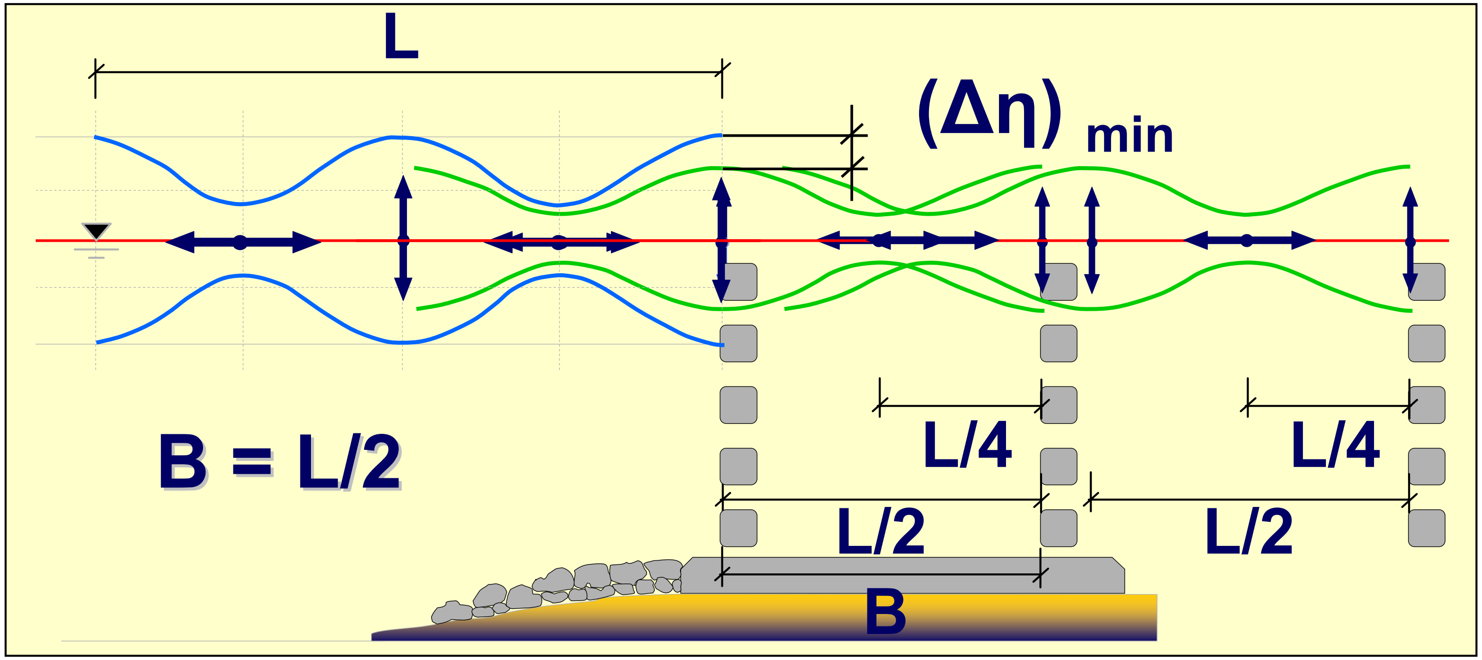
Shorter Period Waves (larger h/L)



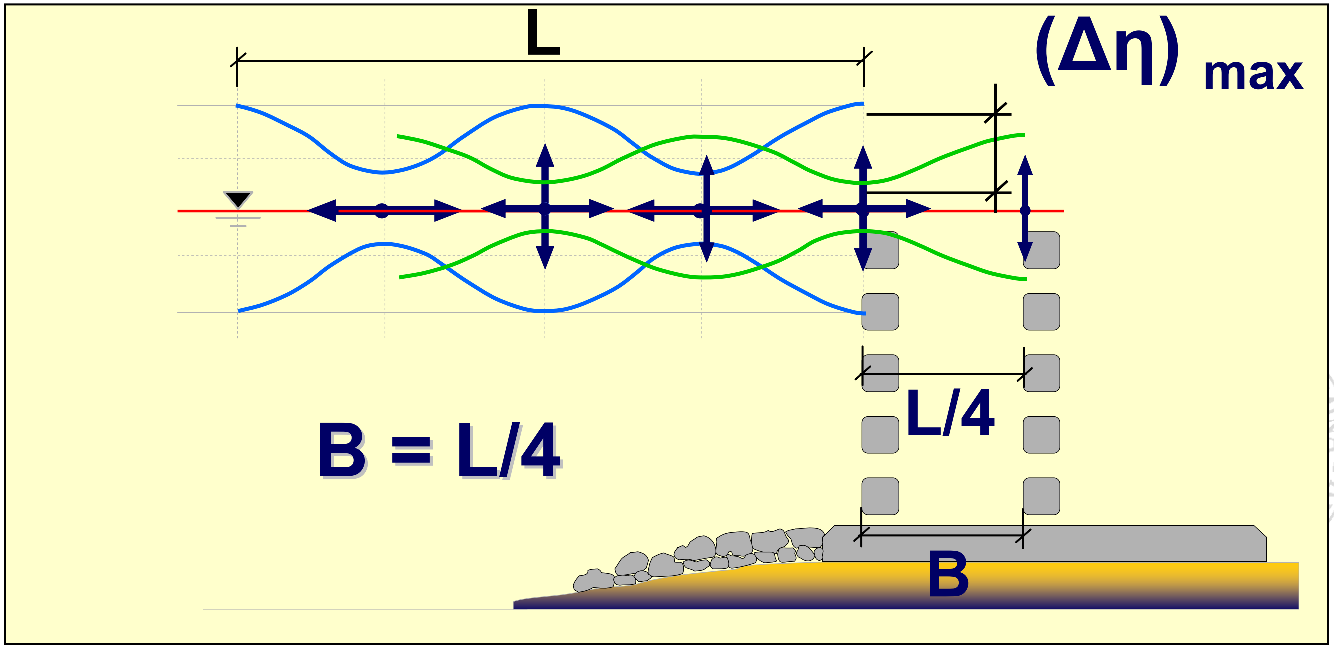
Longer Period Waves (smaller h/L)



Differences Related to the Involved Processes (4)

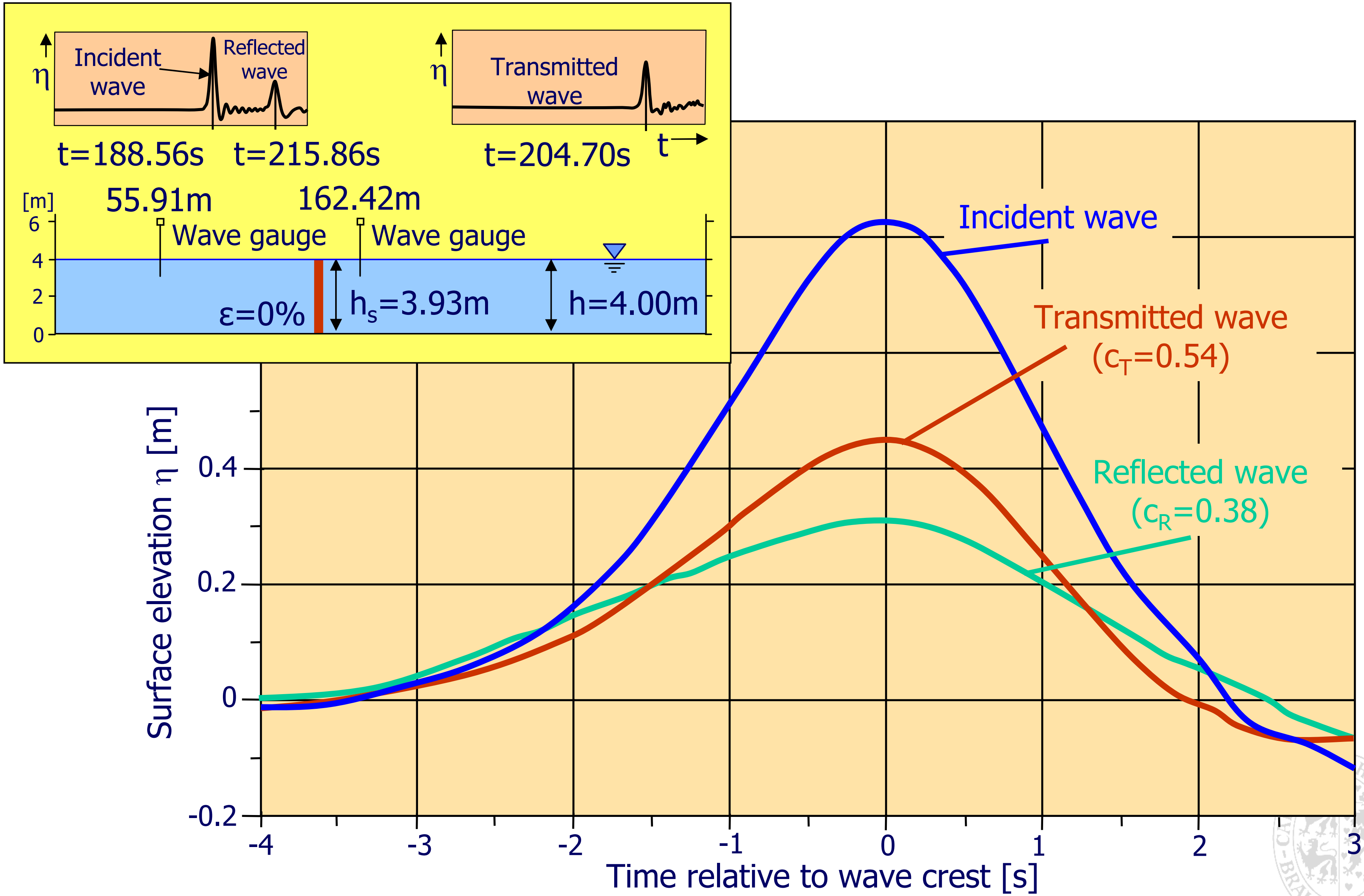


Effect of Phase Shift on the performance of Submerged Progressive Filter Systems



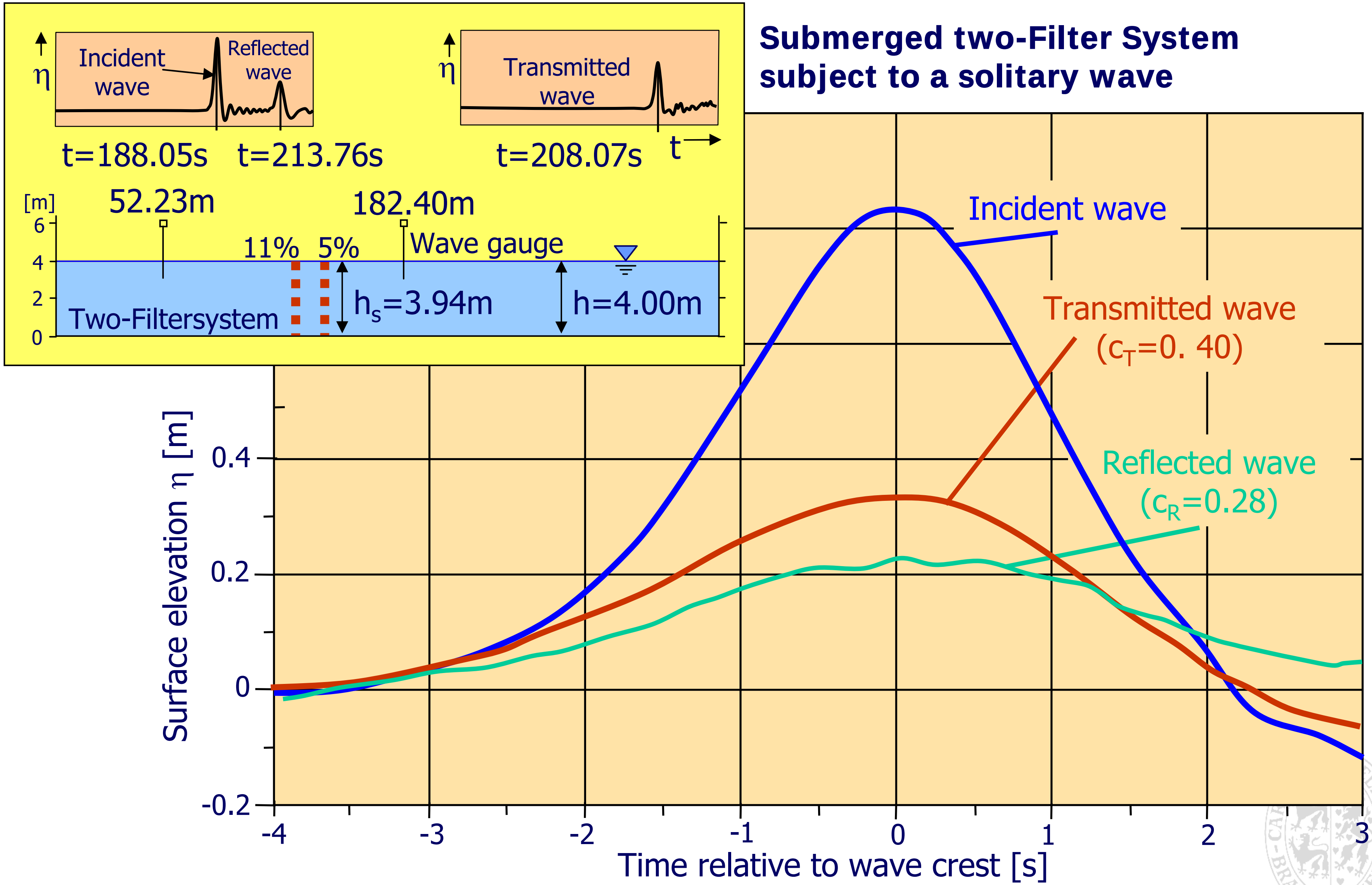
Hydraulic Performance for Solitary Waves

Performance of Submerged impermeable single Wall subject to solitary waves

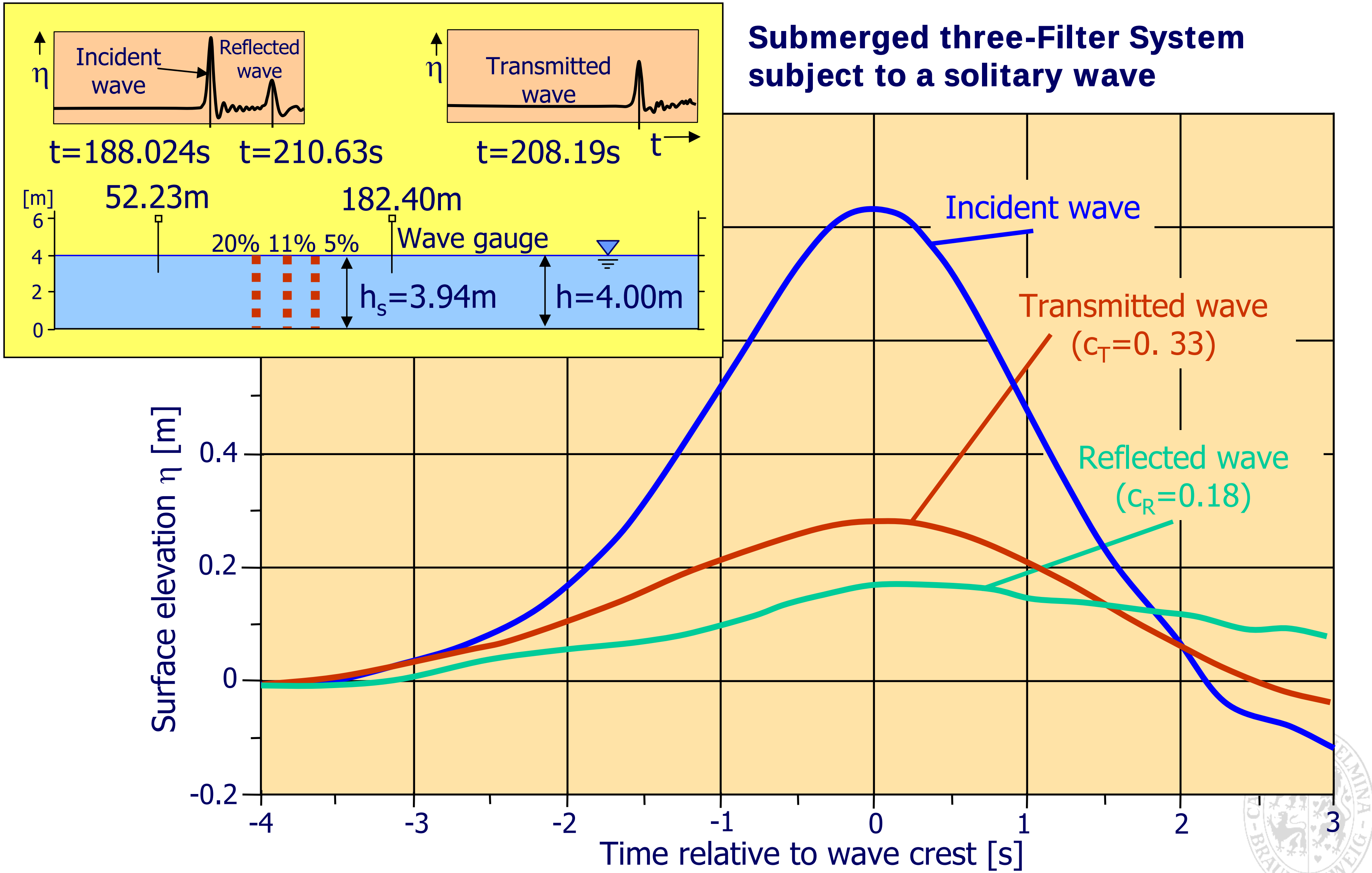


Performance of Two-Filter-Reef System for Solitary Waves

Submerged two-Filter System subject to a solitary wave

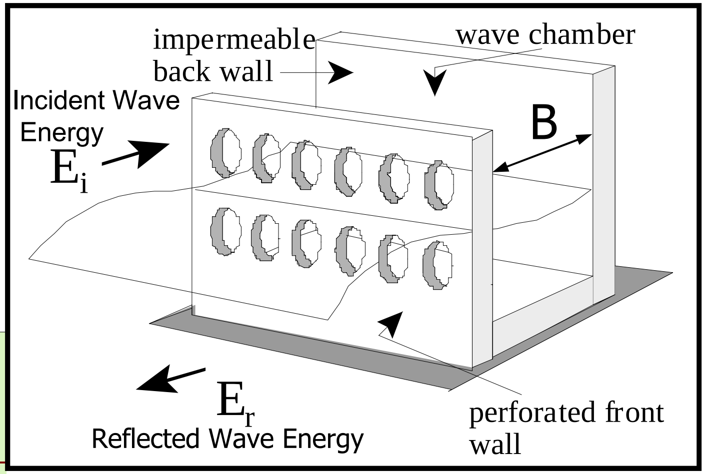


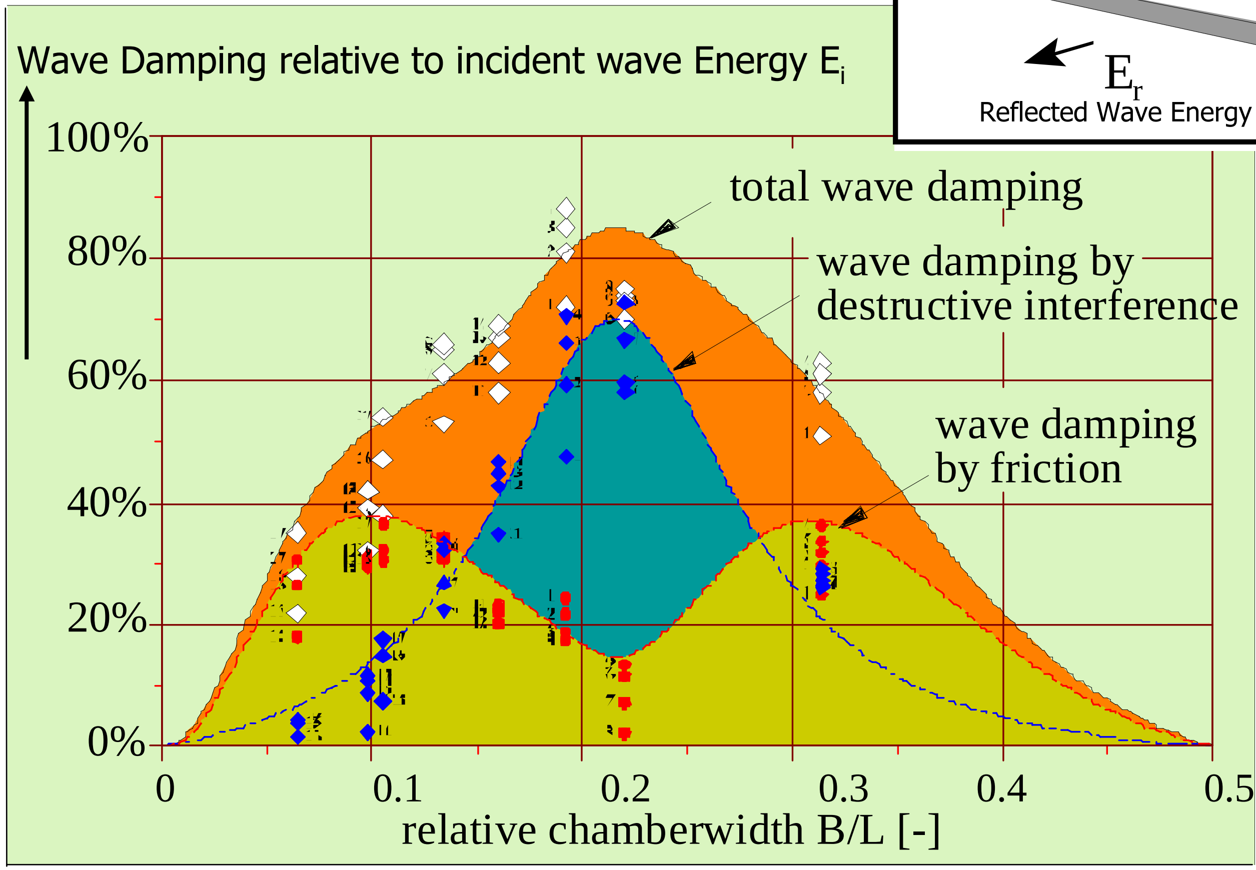
Performance of Three-Filter-Reef System for Solitary Waves



Surface Piercing Wave Absorbers as Seawalls and Breakwaters

Wave Damping at One Chamber System (OCS)



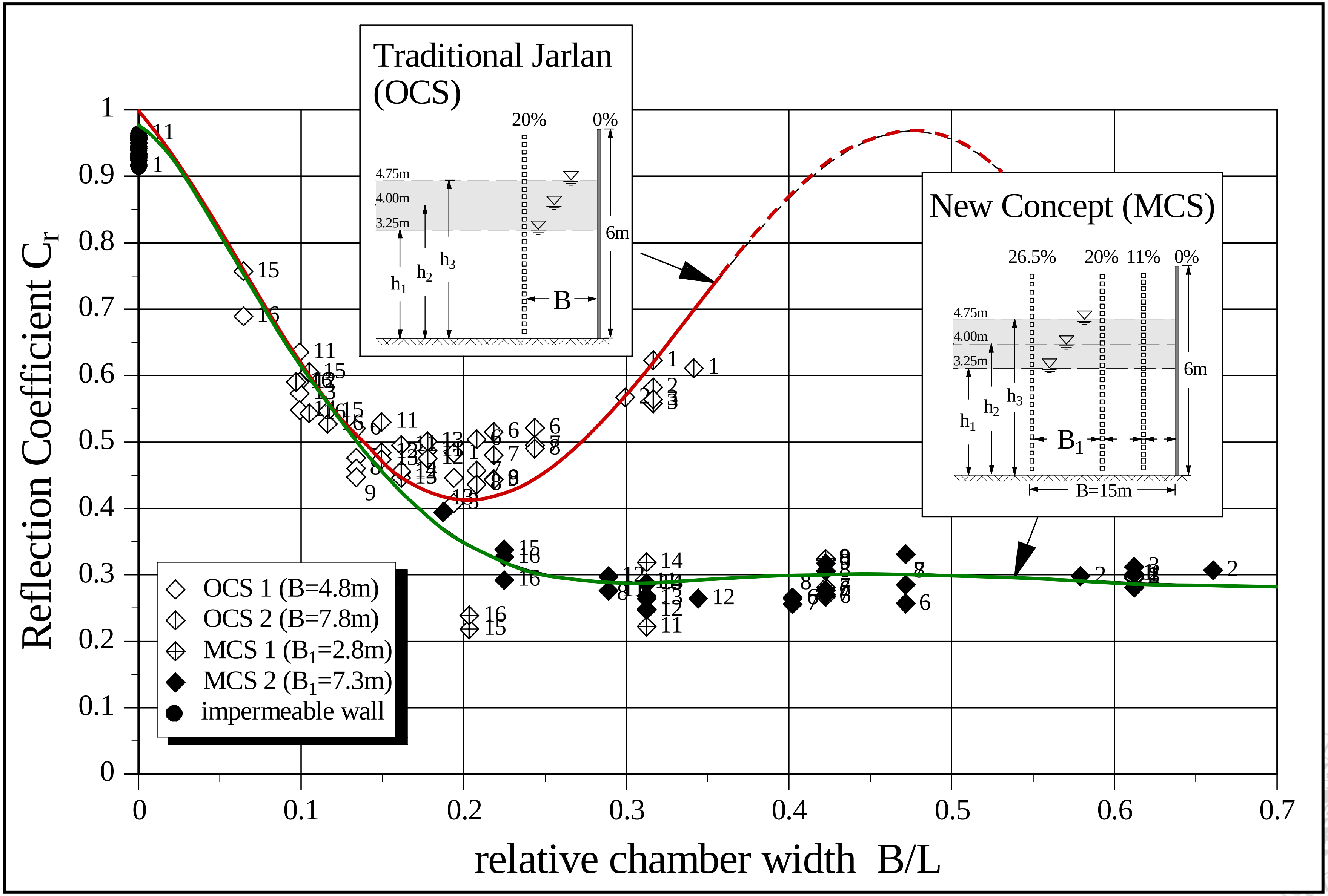


Front Wall of Wave Absorber in GWK

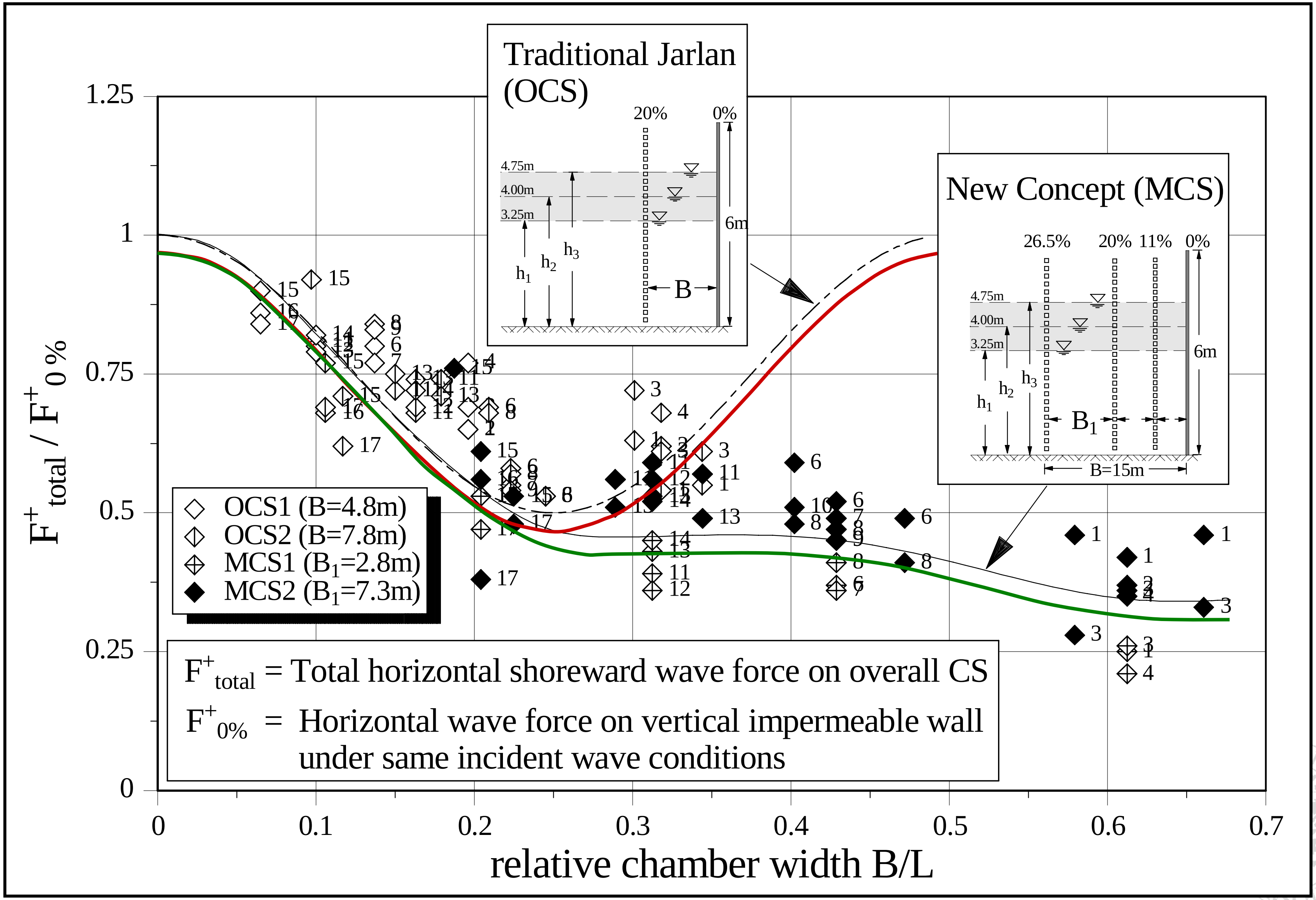
Breaking Wave on Wave Absorber in GWK

Waves Absorbers Under Freak Wave Loading (Video)

Reflection Coefficient of OCS and MCS

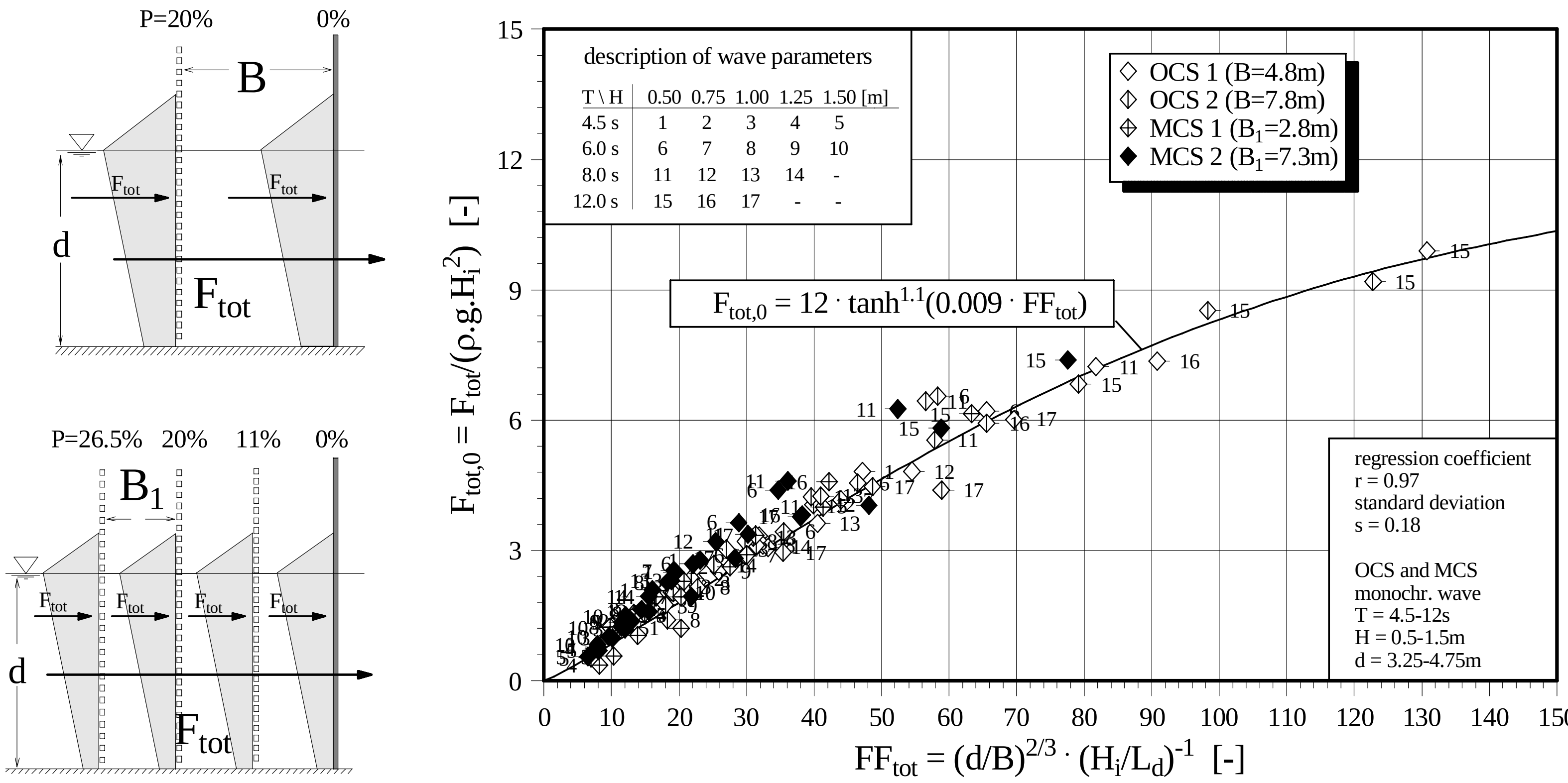


Resultant Horizontal Wave Forces on OCS and MCS



Overall Load on One and Multi Chamber System

Overall Load on One and Multi Chamber Systems



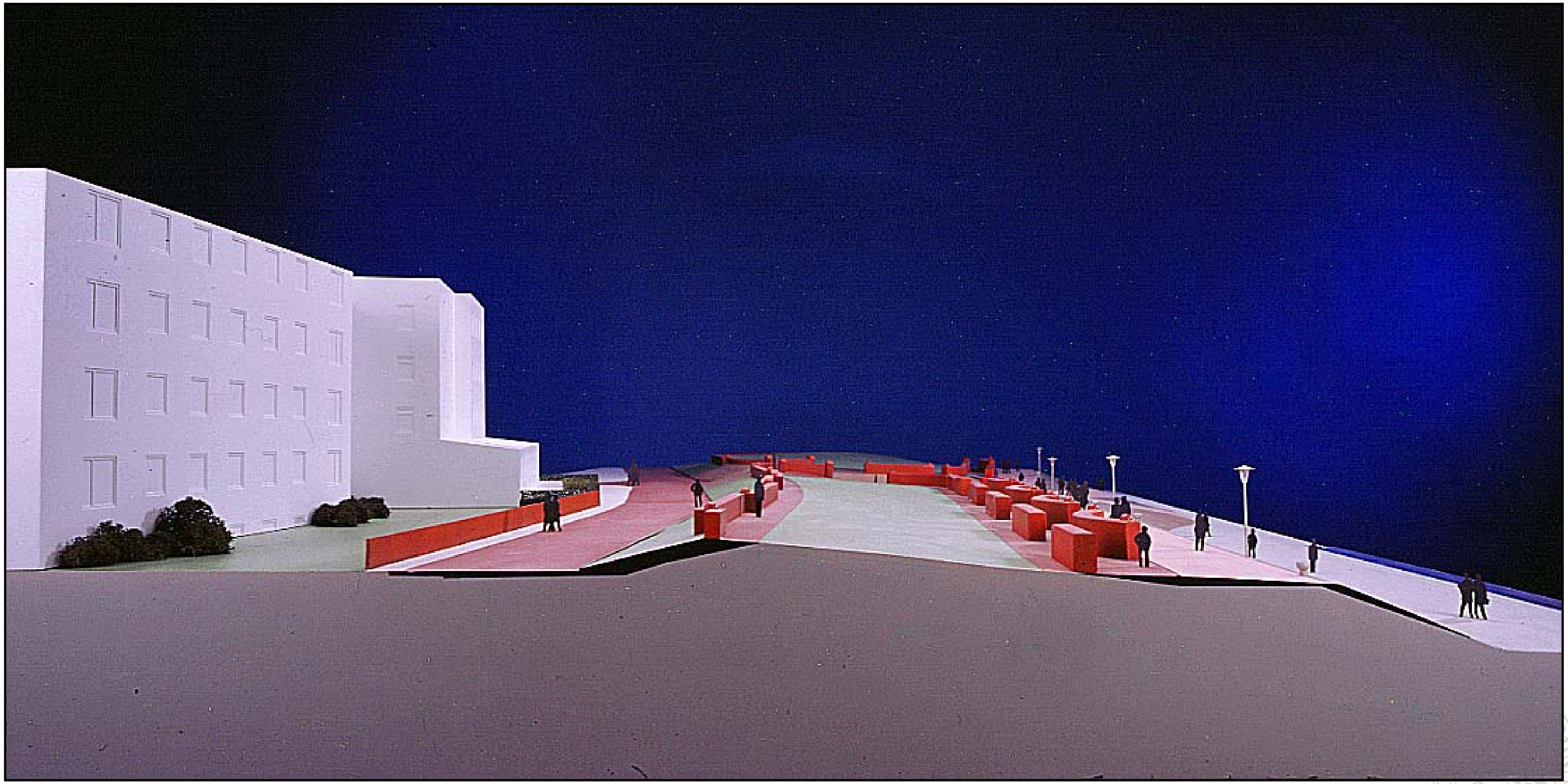
(Oumeraci et al, 2001)

Soft Wave Barriers for Coastal Protection

References:

- Oumeraci, H.; Schüttrumpf, H.; Kortenhaus, A.; Kudella, M.; Möller, J.; Muttray, M. (2002): Large-Scale Model Tests for the Rehabilitation and Extension of the Coastal Protection of the North Beach Area in Norderney. Res. Report no. 853, LWI, TU Braunschweig, (in German)

Design (Computer Model)



Wave Damping Measures Norderney Island (North Sea)

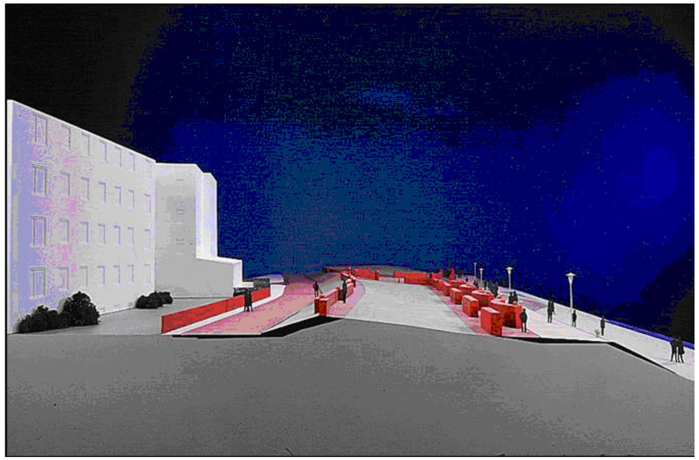
Open Sea Wall on Island Norderney, North Sea (Video)

Application to Tsunami

Objective: ⇒ To progressively weaken tsunami power without completely blocking inundation, but with additional benefit of broadly blocking floating debris.

Application: ⇒ As multi-purpose structures everywhere where planting of coastal forests is not feasible

⇒ Especially appropriate for touristic and urbanized coastal areas where man-made protective structures should be fitted aesthetically into the local marine landscape.

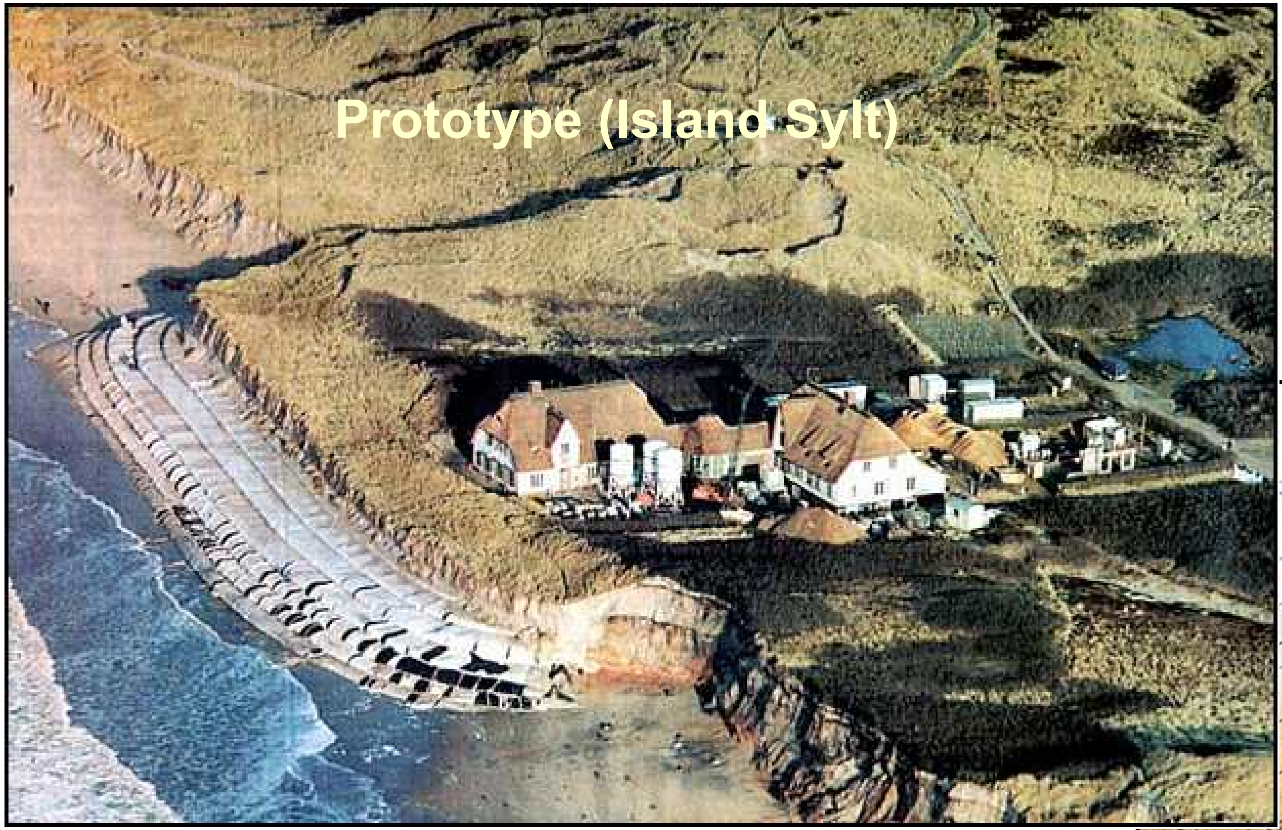


a) Design (Computer Animation)

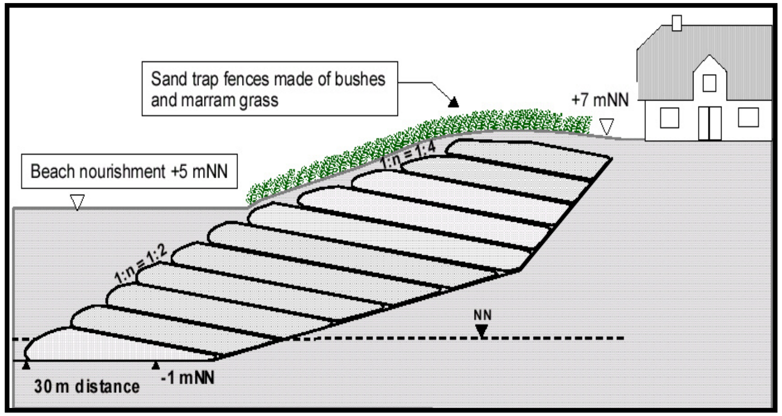
b) Built in Norderney (North Sea)

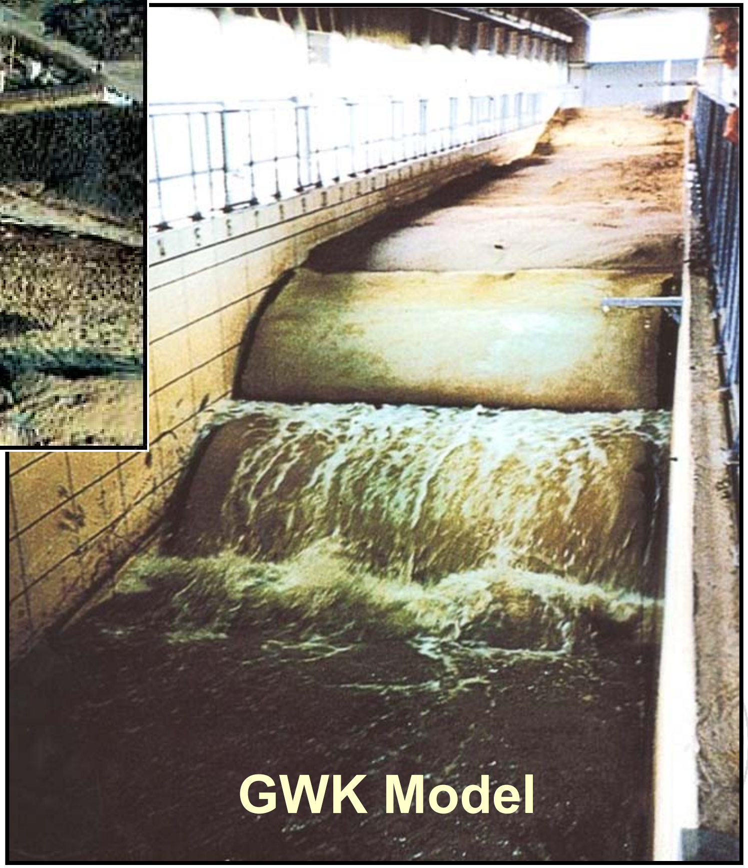
Geotextile Structures for Coastal Protection

Dune Reinforcement and Coastal Protection with Innovative Geotextile



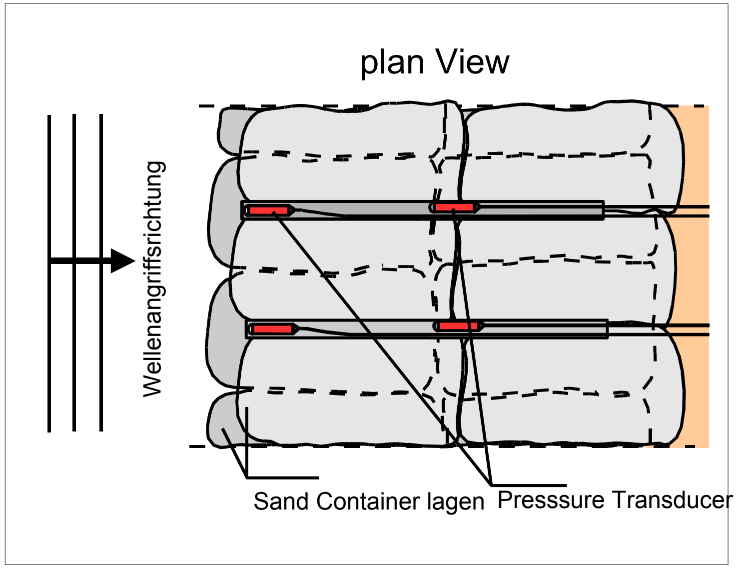
[Picture: Sylt Picture 2000]

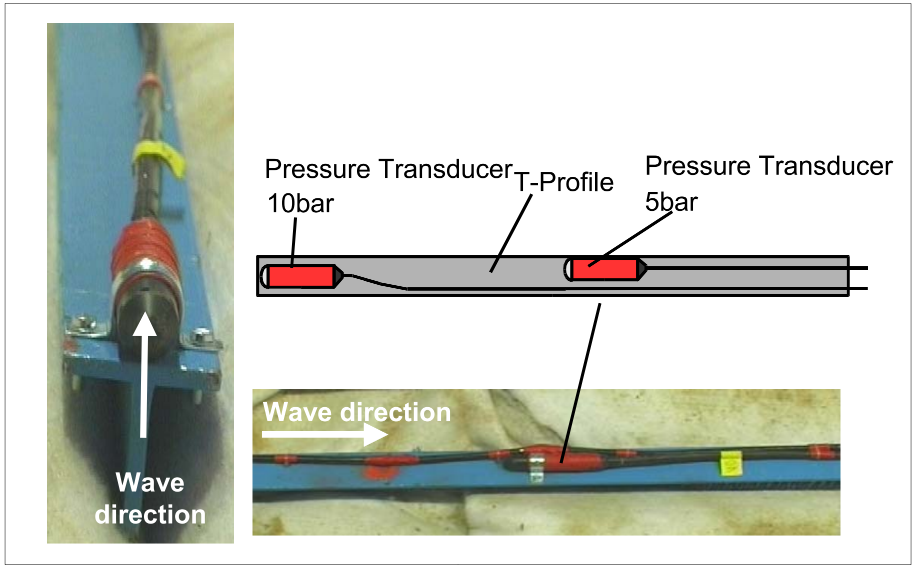


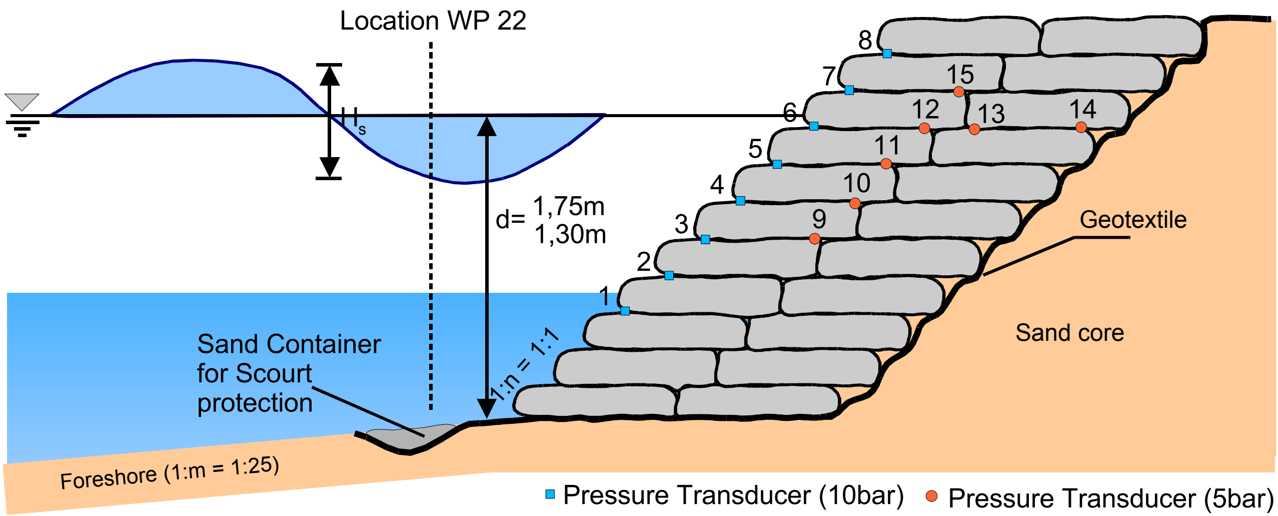


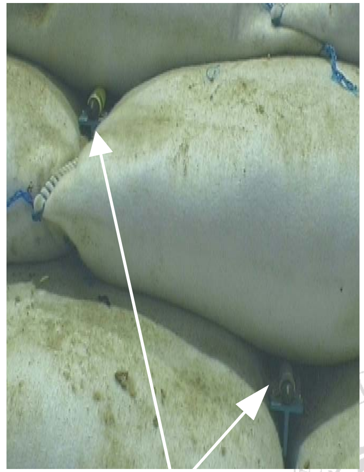
Geotextile Sand Container for Beach Reinforcement

Geotextile Sand Containers for Coastal Protection and Dune Reinforcement: Experimental Set-Up in GWK





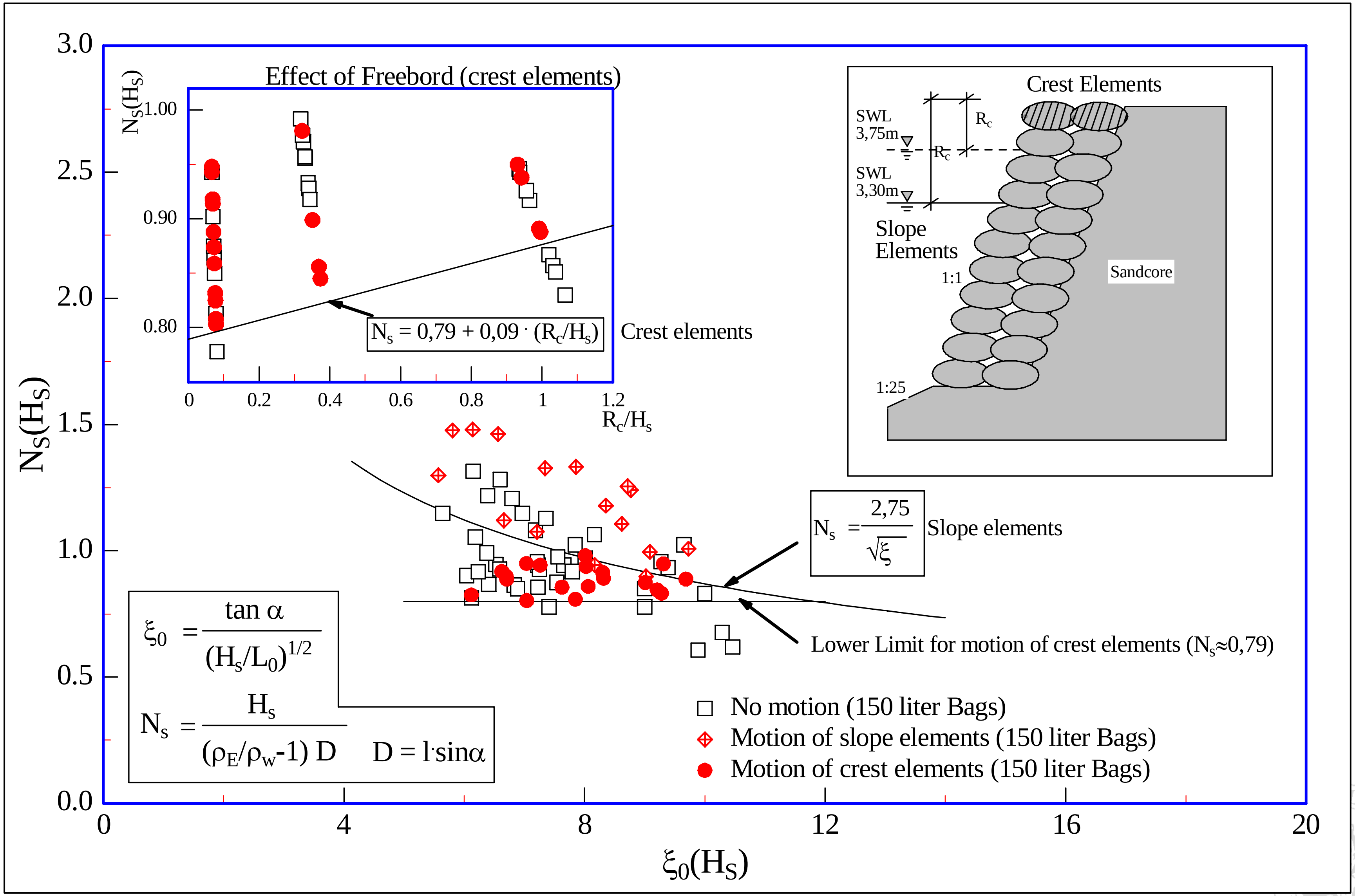




Installed Pressure Transducer
(Frotn view and seaside Dlope)

Geotextile Sand Containers: Tests in GWK (Video)

Hydraulic Stability Formulae for Geotextile Sand Containers



Improved Stability formulae by accounting for Deformation of GSC see PhD-Thesis of J. Recio (2007)

Geotextile Sand Containers: Example Applications


Thank you for your attention!