Hydraulic Performance and Stability of Coastal Defence Structures

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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:

Rubble Mound Breakwater: Model Construction in GWK

Run Up Gauges

Pressure Transducers

h = 4,50 m
H = 1,00 m
T = 6,00 s
Research Strategy for Rubble Mound Breakwaters

1. Nearfield in front of breakwater: \(H_i, H_r, H(x)\)
2. On seaward slope: \(R, H(x), \eta(x), p/\rho g(x, z, t), P/\rho g(x, z)\)
3. Below seaward slope: \(R_C, R_F, \eta_a, \bar{\eta}(x), \Delta \eta/\Delta x, p/\rho g, \text{grad } p/\rho g\)
4. Breakwater core: \(H_0, H(x), P/\rho g(z), p/\rho g(z), K_t\)
5. Nearfield at lee side: \(K_t, \Delta E/E_i\)
Wave-Induced Pore Pressure Field

Wave parameters:
- $h = 2.49\text{m}$; $T = 5\text{s}$; $H_i = 1.06\text{m}$
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

Dissipated wave energy in the partial standing wave field in front of the breakwater:

\[ 1 - (1 - K_r)^2 \]

\[ (1 - K_r)^2 \]

Relative energy density:

\[ \frac{E}{E_i} [-] \]

- \( K_t^2 \) regular waves
- \( K_t^2 \) wave spectra
- \( K_t^2 + (1 - K_r)^2 \) regular waves
- \( K_t^2 + (1 - K_r)^2 \) wave spectra

Relative width:

\[ k_0 h \cot \alpha [-] \]
Effect of Core Permeability on Hydraulic Stability and Performance of Rubble Mound Breakwater

References:

Twin-Wave Flume at Leichtweiß Institut

- Length ≈ 90m
- Depth = 1.25m

(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 (Synchronous 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

<table>
<thead>
<tr>
<th>Mode of Placement</th>
<th>Description</th>
<th>Darcy’s permeability coefficient k value [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="GSC-structure" /></td>
<td>GSC-structure made of geotextile sand containers placed randomly</td>
<td>$2.412 \times 10^{-2}$</td>
</tr>
<tr>
<td><img src="image2" alt="Gravel structure" /></td>
<td>Structure made of gravel</td>
<td>$3.881 \times 10^{-1}$</td>
</tr>
</tbody>
</table>
Stability Number: Geo-Core vs. Traditional Breakwater

**Geo – Core Breakwater**

\[ D_{f,G} = 5.0 \cdot 10^{-5} \cdot \left( N_s \cdot s_m^{-1/3} \right)^{5.1435} \]

**Traditional Breakwater**

\[ D_{f,T} = 5.0 \cdot 10^{-5} \cdot \left( N_s \cdot s_m^{-1/3} \right)^{4.5141} \]

\[ s_m = \frac{H_s}{L_m} \quad \text{local wave steepness} \]

\[ N_s = \frac{H_s}{\left( \frac{\rho_s}{\rho_w} - 1 \right) D_{m50}} \]

\[ N_{od} = \text{Number of displaced rock units} \]

\[ N_a = \text{Number of rock units in the upper armour layer} \]
**$K_D$ - Value in HUDSON-Formula for Traditional Breakwater**

**HUDSON Formula:**

$$W_{so} = \frac{\rho_s \cdot g \cdot H_s^3}{K_D \left( \frac{\rho_s}{\rho_w} - 1 \right)^3 \cot \alpha}$$

**Equation:**

$$K_D = f \left( \frac{H_s}{L_m}, D_f \right)$$

**Calculations:**

- $S_p = \frac{H_s}{L_p}$
- $\text{Damage } D_f = \frac{3}{2} (\text{Slope} \cdot \frac{1}{2})$
- $K_D = 1.12$

**Graph:**

- Slope $1:1.5$ $sp=0.03$
- Slope $1:1.5$ $sp=0.05$
- Slope $1:2$ $sp=0.03$
- Slope $1:2$ $sp=0.05$
$K_D = f\left(\frac{H_s}{L_m}, D_f\right)$

HUDSON Formula:

$W_{50} = \frac{\rho_s \cdot g \cdot H_s^3}{K_D} \left(\frac{\rho_s}{\rho_w} - 1\right)^3 \cot \alpha$

$s_m = \frac{H_s}{L_m}$

$K_D = 1.12$
Stability Number for the Rear Side

\[ D_f = 0.3455 \cdot \left( \frac{R_c}{H_{mo}} \right)^{-0.155} \]

Both Breakwaters

- Traditional Breakwater
- Geo-Core Breakwater
- Total Damage (Geo-Core)

Damage \( D_f \) vs. Freeboard \( \frac{R_c}{H_{mo}} \).
Wave Overtopping Performance

Traditional Breakwater

\[ \frac{Q}{(2gH_{mo}^3)^{0.5}} = 0.096 \exp(-3.103R) \]

\[ R^* = R_c/H_{m0}^{1/\gamma} \]

\[ R^2 = 0.928 \]

Geo-Core Breakwater

\[ \frac{Q}{(2gH_{mo}^3)^{0.5}} = 0.096 \exp(-2.81R) \]

\[ R^* = R_c/H_{m0}^{1/\gamma} \]

\[ R^2 = 0.967 \]
Wave Reflection Performance

\[ k_r \approx \frac{\pi}{\pi} \]

\[ k_c = 0.42 \tan \alpha / (k_0 d)^{0.5} \]

\[ k_0 = 2\pi L_0 \]

(Regression according to Oumeraci and Muttray, 2001)
Wave Transmission Performance

Traditional Breakwater

\[ k_f = 0.001 \cdot \frac{R_C}{H_S} \left( \frac{s_m}{2\pi} \right)^{0.5} \]

\[ R^2 = 0.756 \]

Geo-Core Breakwater

\[ k_f = 0.011 \cdot \frac{R_C}{H_S} \left( \frac{s_m}{2\pi} \right)^{0.5} \]

\[ R^2 = 0.890 \]

\[ s_m = \frac{H_S}{L_m} \]
Hydraulic Performance of an Artificial Reef with Rectangular Shape

References:

Incident Waves

Wave Breaking at Reef

Higher Harmonics behind Reef
Position of the Problem

Present design: \( C_t = \frac{H_t}{H_i} \) (1) and \( C_t^2 + C_r^2 + C_d^2 = 1 \) (2)

However:

- Shift of wave energy towards higher frequencies behind reef

\[ \downarrow \]

Equations (1) and (2) not sufficient to describe hydraulic performance
Experimental Set-Up in the Wave Flume of LWI

- Wave maker
- Wave gauges (14)
- ADV-probes (3)
- Pressure gauges (11)
- ADV-computer (digital/analog conversion)
- A/D-converter (National Instruments AT-MIO-64)
- main data acquisition
- data back-up on CD-Rom
- data back-up on CD-Rom
- digital video camera for test documentation (Canon XM 1)
- video data on digital cassettes
- test log: visual impression and special observation
- data analysis
- digitalisation if required
- analog signal for data synchronisation

CCD-Camera for PIV measurement (The Imaging Source DMP 60 H 13)

Glass window

Wave absorbing rubble mound

Black Separation Wall

h = 0.4 - 0.6 m

B = 0.5 - 1.0 m

3.00 m

16.00 m

0.15 m

1.85 m

81.00 m
### Wave Transformation at a Reef

#### Incident Wave Spectrum at Gauge Array 2

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Amplitude [m^2/Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66</td>
<td>0.06</td>
</tr>
</tbody>
</table>

#### Reflected Wave Spectrum at 2

<table>
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<th>Frequency [Hz]</th>
<th>Amplitude [m^2/Hz]</th>
</tr>
</thead>
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<td>0.66</td>
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</table>

#### Transmitted Wave Spectrum at 3

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Amplitude [m^2/Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66</td>
<td>0.06</td>
</tr>
<tr>
<td>1.33</td>
<td>0.04</td>
</tr>
</tbody>
</table>

#### Regular Wave

- **(Hs = 0.12; T = 1.5s)**

#### Irregular Wave

- **(Hs = 0.12; T = 1.5s)**
Effect of Relative Submergence Depth $d_r/H_i$ on Hydraulic Performance

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

Transmission Coefficient $C_t$
- $C_t = 1.0 - 0.83 \cdot \exp(-0.72 \cdot d_r/H_i)$
- $\sigma' = 6.7\%$

Reflection Coefficient $C_r$
- $C_r = 0.57 \cdot \exp(-0.23 \cdot d_r/H_i)$
- $\sigma' = 26.5\%$

Dissipation Coefficient $C_d$
- $C_d = 0.80 \cdot \exp(-0.27 \cdot d_r/H_i)$

The graph shows the variation of $C_t$, $C_r$, and $C_d$ with relative submergence depth $d_r/H_i$. The data points are fitted with the exponential equations provided above.
## Influencing Parameters on Hydraulic Performance

### Multiple Regression Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
<th>Simplified $(d_r/H_i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>$C_t = 0,5 + 0,5 \cdot \cos\left(0,48 \left(\frac{B}{L_i}\right)^{0,15} \left(\frac{H}{L_i}\right)^{-0,35} \left(\frac{d_r}{H_i}\right)^{-0,7}\right)$</td>
<td>$C_t = 1,0 - 0,83 \cdot \exp\left[-0,72 \cdot (d_r/H_i)\right]$</td>
</tr>
<tr>
<td></td>
<td>$\sigma'(C_t) = 4,6%$</td>
<td>$\sigma'_t = 6,7%$</td>
</tr>
<tr>
<td>Reflection</td>
<td>$C_r = 0,5 + 0,5 \cdot \cos\left(2,66 \left(\frac{B}{L_i}\right)^{0,01} \left(\frac{H}{L_i}\right)^{0,125} \left(\frac{d_r}{H_i}\right)^{0,2}\right)$</td>
<td>$C_r = 0,57 \cdot \exp\left[-0,23 \cdot (d_r/H_i)\right]$</td>
</tr>
<tr>
<td></td>
<td>$\sigma'(C_r) = 12,3%$</td>
<td>$\sigma'_r = 26,5%$</td>
</tr>
<tr>
<td>Dissipation</td>
<td>$C_d = 0,5 + 0,5 \cdot \cos\left(1,77 \left(\frac{B}{L_i}\right)^{-0,1} \left(\frac{H}{L_i}\right)^{0,14} \left(\frac{d_r}{H_i}\right)^{0,45}\right)$</td>
<td>$C_d = 0,80 \cdot \exp\left[-0,27 \cdot (d_r/H_i)\right]$</td>
</tr>
<tr>
<td></td>
<td>$\sigma'(C_d) = 10,5%$</td>
<td>$\sigma'_d = 16,4%$</td>
</tr>
</tbody>
</table>
Effect of Relative Submergence Depth $d_r/H_i$ on Periods of Transmitted Waves

$T_{01} = \frac{m_0}{m_1} = \frac{\int S(f)df}{\int S(f)df}$

$C_{T_{01}} = \frac{(T_{01})_t}{(T_{01})_i}$

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

$C_{T_{-10}} = \frac{(T_{-10})_t}{(T_{-10})_i}$

$C_{T_{01}} = 1.0 - 0.36 \cdot \exp(-0.58 \cdot \frac{d_r}{H_i})$; $\sigma' = 4.7\%$

$C_{T_{-10}} = 1.0 - 0.24 \cdot \exp(-0.63 \cdot \frac{d_r}{H_i})$; $\sigma' = 3.0\%$
Description of Transmitted Wave Spectrum by Three Spectral Parameters

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

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

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

where \( m_n = \int S(f) f^n df \); \( T_{01} = \frac{m_0}{m_1} \) and \( T_{-10} = \frac{m_{-1}}{m_0} \)
Breaking Criterion and Breaker Types

Modified MICHE Criterion

\[(H_i / L_f)_{two} = 1.43 \cdot (d_r / L_f)\]

Bleck 2002

\[(H_i / L_f)_{two} = 0.142 \cdot \tanh(M_k \cdot 2\pi \cdot d_r / L_f)\]

\[M_k = 0.735\]

Breaker Types

- Non-Breaking
- Spilling Breaker
- Two-Phase Breaker
- Drop-Type Breaker

\[M_k = 0.735\]
**Breaker Types on Reefs: Energy Dissipation**

\[ C_d = \sqrt{\frac{E_d}{E_i}} \]

with \( E_d, E_i \) = dissipated and incident wave energy.

<table>
<thead>
<tr>
<th>Spilling breaker</th>
<th>Two-Step breaker</th>
<th>Drop-type breaker</th>
</tr>
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<tbody>
<tr>
<td><img src="image1" alt="Spilling breaker" /></td>
<td><img src="image2" alt="Two-Step breaker" /></td>
<td><img src="image3" alt="Drop-type breaker" /></td>
</tr>
</tbody>
</table>

- \( C_d = 0.4 \div 0.60 \)  
  \( (\bar{C}_d \approx 0.55)* \)

- \( C_d = 0.35 \div 0.85 \)  
  \( (\bar{C}_d \approx 0.54) \)

- \( C_d = 0.4 \div 0.90 \)  
  \( (\bar{C}_d \approx 0.68) \)

* Non-Breaking waves: \( \bar{C}_d = 0.33 \)
### Breaker Types on Reefs: Energy Dissipation

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</thead>
</table>

<p>| | | |</p>
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<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Spilling breaker diagram" /></td>
<td><img src="image2.png" alt="Two-Step breaker diagram" /></td>
<td><img src="image3.png" alt="Drop-type breaker diagram" /></td>
</tr>
</tbody>
</table>

- **Spilling breaker**
  - $C_d = 0.4 \div 0.6$
  - $(C_d \approx 0.55)^*$

- **Two-Step breaker**
  - $C_d = 0.35 \div 0.85$
  - $(C_d \approx 0.54)$

- **Drop-type breaker**
  - $C_d = 0.4 \div 0.90$
  - $(C_d \approx 0.68)$

* Non-Breaking waves: $C_d = 0.33$
Vortex Losses

a) Seaward Upper Vortex
   - Reef induced current deflection
   - Seaward upper vortex

b) Leeward Lower Vortex
   - Wave induced orbital velocity
   - Leeward lower vortex

(c) Seaward Lower Vortex
   - Seaward lower vortex

(d) Leeward Upper Vortex
   - Reef induced current deflection
   - Leeward upper vortex
Non-Linear Effects with Wind Waves for $B/L = 0.16$

- $dr = 0.20m$
- $B = 0.50m$
- $h = 0.50m$
- $B/L = 0.16$

$H/L = 0.04 \Rightarrow d/H = 1.6; \quad B/L = 0.16$

$t = T + 0.25s$

$t = T + 1.00s$
Non-Linear Effects with Wind Waves for $B/L = 0.32$

Water surface elevation [m]  spectrum

Reef

$H/L_1 = 0.04 \Rightarrow d_H = 1.6; B/L_1 = 0.32$

$H/L_1 = 0.04 \Rightarrow d_H = 1.6; B/L_1 = 0.32$

$t = T + 0.25s$

$t = T + 1.00s$
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

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

Very Large Artificial Reef

Sand fill 250m³

colonised by reef organisms (only after few months)
Hydraulic Performance of Wave Absorbers
Submerged Wave Absorbers as Artificial Reefs for Coastal Protection
Experimental and Theoretical Investigations for Storm Waves

References:


Submerged Wave Absorbers for Beach Protection

Coastline

Tourist Activities

„Fun“-Waves

Three-Filter-System

20% 11% 5%
Experimental Set-Up in Large Wave Flume Hannover (GWK)

- **Single Screen**
  - Structure Height: \( d_B = 3.94 \) m
  - \( \varepsilon = 0\%, 5\%, 11\%, 20\% \)

- **Two-Filter-System**
  - Structure Height: \( d_B = 3.94 \) m
  - \( \varepsilon = 5\%, 11\% \)

- **Three-Filter-System**
  - Structure Height: \( d_B = 3.94 \) m
  - \( \varepsilon = 5\%, 11\%, 20\% \)

⇒ Wave Heights: \( H_s = 0.5 \text{m} - 1.5 \text{m} \)
⇒ Wave Periods: \( T_p = 3 \text{s} - 12 \text{s} \)
### Measuring Devices at the Wall

#### Single Screen $\varepsilon = 5\%$
- Pressure Transducers (20)
- Force Transducers (10)
- ADV (3D) (3)
- Micro-Propeller Current Meters (4)

#### Measured Values

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.42</td>
</tr>
<tr>
<td>1</td>
<td>0.61</td>
</tr>
<tr>
<td>2</td>
<td>0.80</td>
</tr>
<tr>
<td>3</td>
<td>0.99</td>
</tr>
<tr>
<td>4</td>
<td>1.18</td>
</tr>
<tr>
<td>5</td>
<td>1.37</td>
</tr>
<tr>
<td>6</td>
<td>1.56</td>
</tr>
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<td>7</td>
<td>1.75</td>
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<tr>
<td>8</td>
<td>1.94</td>
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<td>9</td>
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<td>11</td>
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<td>3.27</td>
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<td>16</td>
<td>3.46</td>
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<tr>
<td>17</td>
<td>3.65</td>
</tr>
<tr>
<td>18</td>
<td>3.84</td>
</tr>
</tbody>
</table>

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![Image of measuring devices at the wall](image-url)
Contribution of Each Filter to Total Wave Damping
Analytical Flow Model

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

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

⇒ Velocity Potential

⇒ 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.)

\[ \frac{\partial \phi_1}{\partial x} = \frac{\partial \phi_2}{\partial x} = -i S(\phi_2 - \phi_1) \]

\( S \) = Structure Parameter including drag, inertia and vortex losses
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. \( C_D^* \)

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

Vortex Loss
\( C_v \) by Stiassnie et al. (1984)

Linearisation

\[ f_D = f_D(C_D^*) \]

Modified Inertia Coeff. \( C_I^* \)

\[ f_I = C_I^* \]

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

\[ f_V = f_V(C_v^*) \]

\[ S = \frac{1}{(f_D + f_V) - i f_I} \]
Calculated Reflected and Transmitted Wave Spectra by Reef

(a) Two filter System

(b) Three filter System
Model Validation for Irregular Waves

- **T_p = 3.50s**
- **H_s = 0.50m**
- **h = 4.00m**

**Graphs:**
- Measured vs. Calculated Reflection Coefficient (Cr)
- Comparison of Measured and Calculated Data for Different Frequencies

**Data Points:**
- **2FS**
  - σ_ε^* = 17%
  - a_xy = 0.93
- **3FS**
  - σ_ε^* = 26%
  - a_xy = 1.00

**Additional Observations:**
- **Energy Density**
  - 2FS σ_ε^* = 6%
  - 3FS σ_ε^* = 5%
  - a_xy = 1.03
- **axy** values vary with wave conditions.
Differences between Short and Longer Waves
Differences Related to the Involved Processes (1)

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)
Differences Related to the Involved Processes (2)

Shorter Period Waves (larger $h/L$)
- Flow field actively involved in wave transmission process
- Particle Orbits only slightly distorted

Longer Period Waves (smaller $h/L$)
- Strongly Distorted Particle Orbits
Differences Related to the Involved Processes (3)

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

- $B = L/2$
  - $(\Delta \eta)_{\text{min}}$
  - $B = L/4$
  - $(\Delta \eta)_{\text{max}}$

$L$
Hydraulic Performance for Solitary Waves
Performance of Submerged impermeable single Wall subject to solitary waves

Incident wave

Reflected wave

Transmitted wave

\[ \eta = 0\% \]

\[ h_s = 3.93 \text{ m} \]

\[ h = 4.00 \text{ m} \]

Time relative to wave crest [s]

Surface elevation \( \eta \) [m]

\[ t = 188.56 \text{ s} \]

\[ t = 215.86 \text{ s} \]

\[ t = 204.70 \text{ s} \]

\[ 55.91 \text{ m} \]

\[ 162.42 \text{ m} \]

\[ (c_T = 0.54) \]

\[ (c_R = 0.38) \]
Performance of Two-Filter-Reef System for Solitary Waves

Submerged two-Filter System subject to a solitary wave

Incident wave

Transmitted wave ($c_T = 0.40$)

Reflected wave ($c_R = 0.28$)

Surface elevation $\eta$ [m]

Time relative to wave crest [s]

Incident wave

Reflected wave

Transmitted wave

Wave gauge

Two-Filter system

$h_s = 3.94m$

$h = 4.00m$

52.23m 182.40m

5\% 11\%

$t = 188.05s\ t = 213.76s\ t = 208.07s$
Performance of Three-Filter-Reef System for Solitary Waves

Submerged three-Filter System subject to a solitary wave

Incident wave

Reflected wave

Transmitted wave

Incident wave

Reflected wave

Transmitted wave

(c_T=0.33)

(c_R=0.18)

Surface elevation \( \eta \) [m]

Time relative to wave crest [s]

\( h_s = 3.94 \) m

\( h = 4.00 \) m
Surface Piercing Wave Absorbers as Seawalls and Breakwaters
Wave Damping at One Chamber System (OCS)

Wave damping can be achieved by:
- Friction
- Destructive interference

Total wave damping is shown as a function of the relative chamber width B/L. The diagram illustrates reflected wave energy (E_r) and incident wave energy (E_i) relative to the incident wave energy.

The chart shows the wave damping relative to the incident wave energy E_i as a function of the relative chamber width B/L.

Key points:
- Impermeable back wall
- Perforated front wall

Wave damping by destructive interference and wave damping by friction are depicted on the chart.
Breaking Wave on Wave Absorber in GWK
Waves Absorbers Under Freak Wave Loading (Video)
Resultant Horizontal Wave Forces on OCS and MCS

Traditional Jarlan (OCS)

New Concept (MCS)

\[ F^+_{\text{total}} = \text{Total horizontal shoreward wave force on overall CS} \]
\[ F^+_{0\%} = \text{Horizontal wave force on vertical impermeable wall under same incident wave conditions} \]
Overall Load on One and Multi Chamber System

\[ F_{tot} = \frac{(d/B)^{2/3}}{(H_0/L_d)} \]

\[ F_{tot,0} = F_{tot}/(\rho g H_0^2) \]

\[ F_{tot,0} = 12 \cdot \tanh^{1.1} (0.009 \cdot FF_{tot}) \]

<table>
<thead>
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<th>T/s</th>
<th>H</th>
<th>0.50</th>
<th>0.75</th>
<th>1.00</th>
<th>1.25</th>
<th>1.50</th>
<th>m</th>
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<td>2</td>
<td>3</td>
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<tr>
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<td>16</td>
<td>17</td>
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</table>

regression coefficient
\( r = 0.97 \)
standard deviation
\( s = 0.18 \)

OCS and MCS monochr. wave
\( T = 4.5-12s \)
\( H = 0.5-1.5m \)
\( d = 3.25-4.75m \)

(Oumeraci et al, 2001)
Soft Wave Barriers for Coastal Protection

References:

Wave Damping Structures in Norderney

Design (Computer Model)
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

Prototype (Island Sylt)

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

- **Sand Container for Scour protection**
- **Location WP 22**
- **Foreshore (1:m = 1:25)**
- **Sand Container lagen**
- **Pressure Transducer (10bar)**
- **Pressure Transducer (5bar)**
- **Installed Pressure Transducer (Front view and seaside Dlope)**

- **Wellenangriffsrichtung**
- **T-Profile**
- **Wave direction**

![Diagram](image-url)
Hydraulic Stability Formulae for Geotextile Sand Containers

**Harlehörn - Island Wangerooge 2002**
(North Sea) 5000 Sandcontainer (0.05 m³)

**Glowe - Island Rügen 2002 (Baltic Sea)**
2000 Sand Container (1.50 m³)

**Artificial Reef Kampen /Sylt**
(North Sea) 216 Sand Container (10 m³)

**Narrowneck Reef - Australia**
Mega-Geo-Container (20m×4,80m)
Sand fill 250m³
colonised by reef organisms (only after few months)
Thank you for your attention!