Phase Jump due to Partial Reflection of Irregular Water Waves at Steep Slopes

Supplement to:
„Wave Resonances Detected in a Wave Tank and in the Field“,
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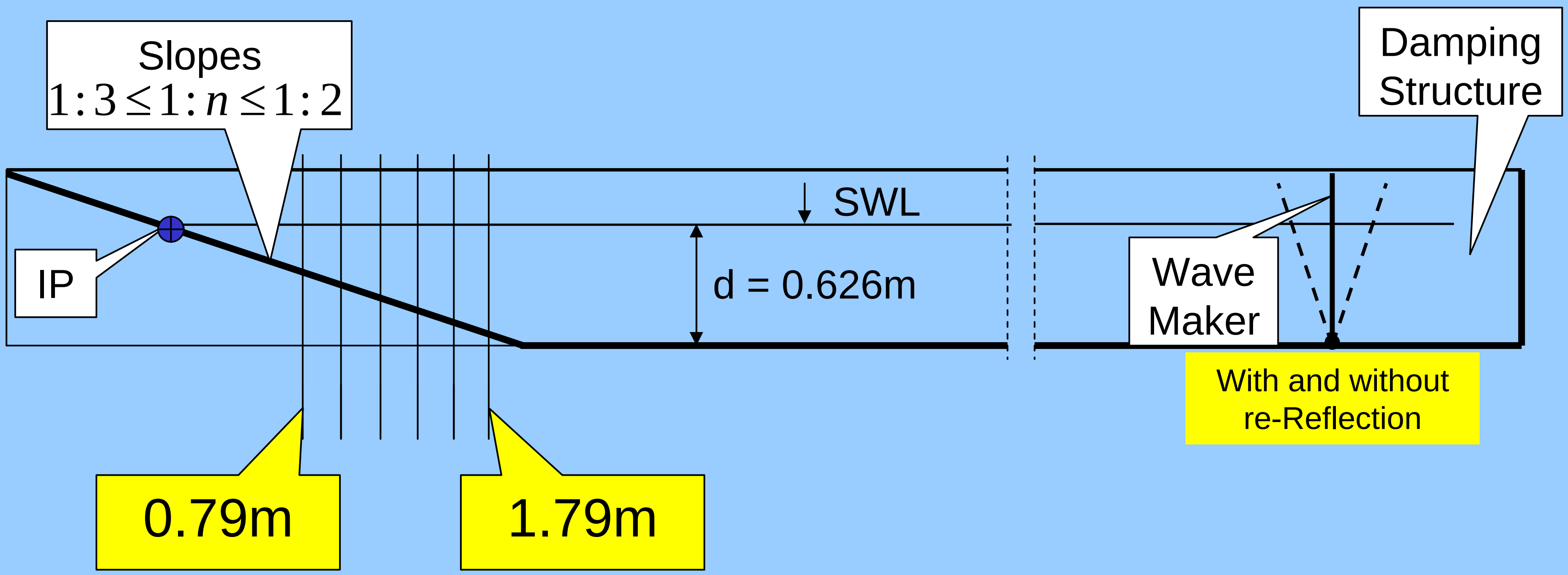
Scope of Presentation

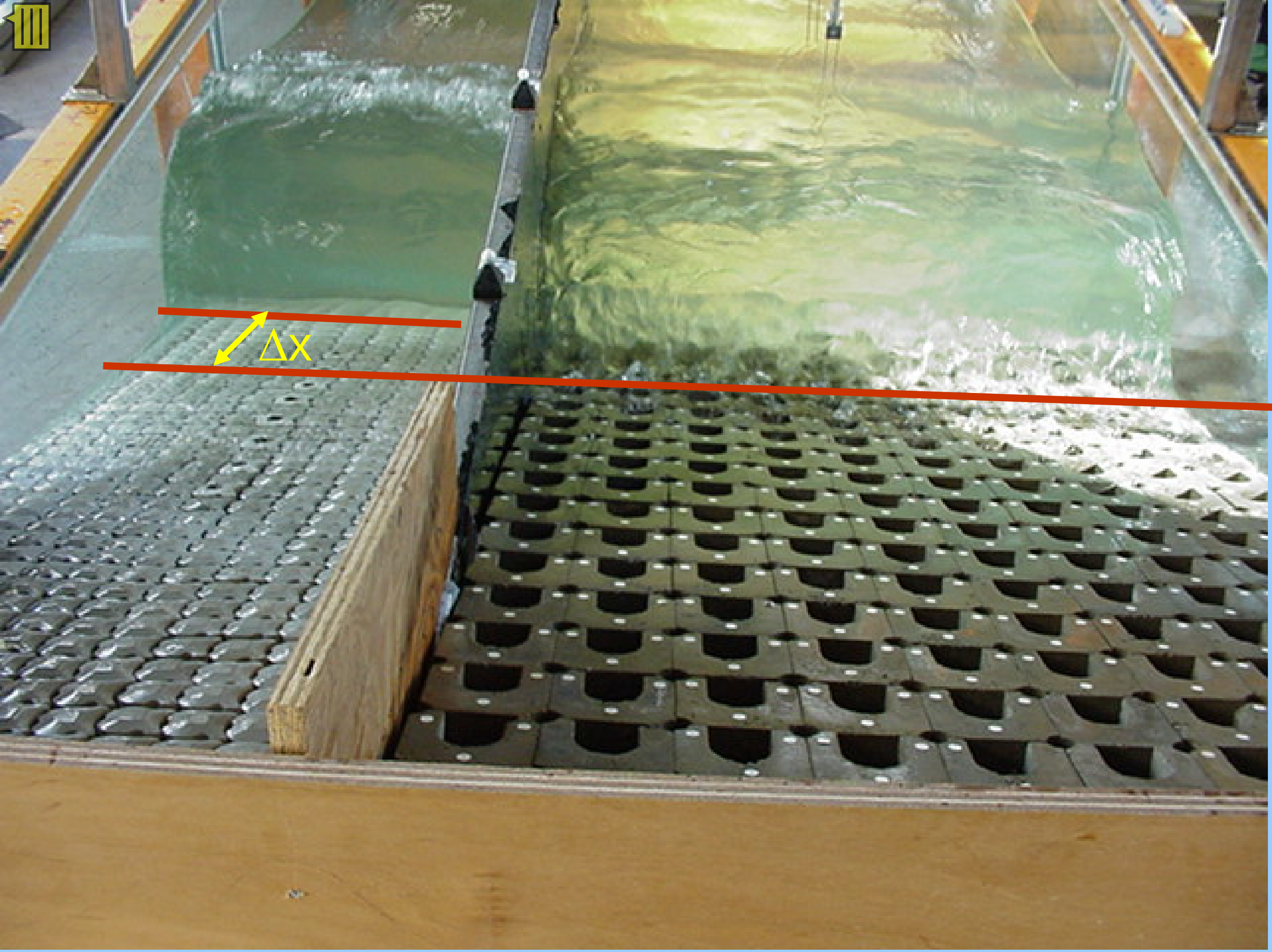
- **Statement:** The process of *wave breaking* at slopes $1:3 \leq 1:n \leq 1:2$ is inextricably linked with the *simultaneous formation* of a ***reflected wave and a wave of transmission***. Superimposition of incident and reflected waves results in the formation of a *partial clapotis* comprising of a ***phase jump***.
- **Analogue:** Fresnel´s Equations describing *reflection and transmission* of light at uniform planar interfaces.
- **Reflection coefficients** $C_r = f(H_r/H_i, \Delta\varphi) < 0$.

Partial standing waves breaking on a slope with reference to the point IP of the still water level intersecting the slope

Main topic: Influence of a phase shift Δφ on breakers interacting with sloping structures



Measurements of water level deflections quasi synchronously at 91 wave probe stations equally spaced 10 cm.



Tests on the stability of Hollow Cubes

Model scale: 1:5

Slopes:
$1:3 \leq 1:n \leq 1:2$

Wave heights up to H = 0.35m

Punging breaker on quasi Smooth Slope

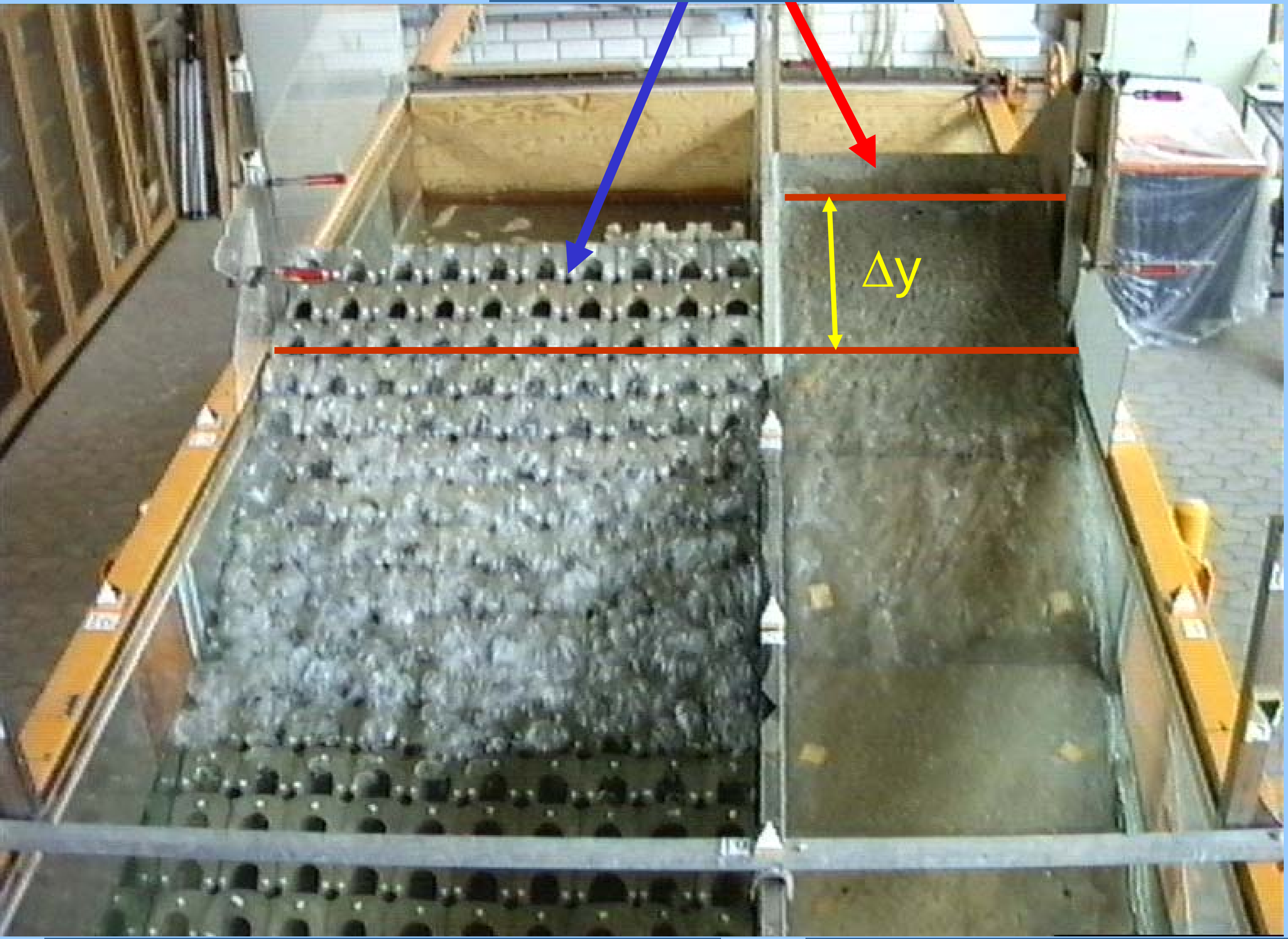
$C_r = -0.32$

Collapsing breaker on Hollow Cubes

$C_r = -0.16$

$\Delta x \approx 0.15m$

Maximum run up



Differences:
- extent
- phase

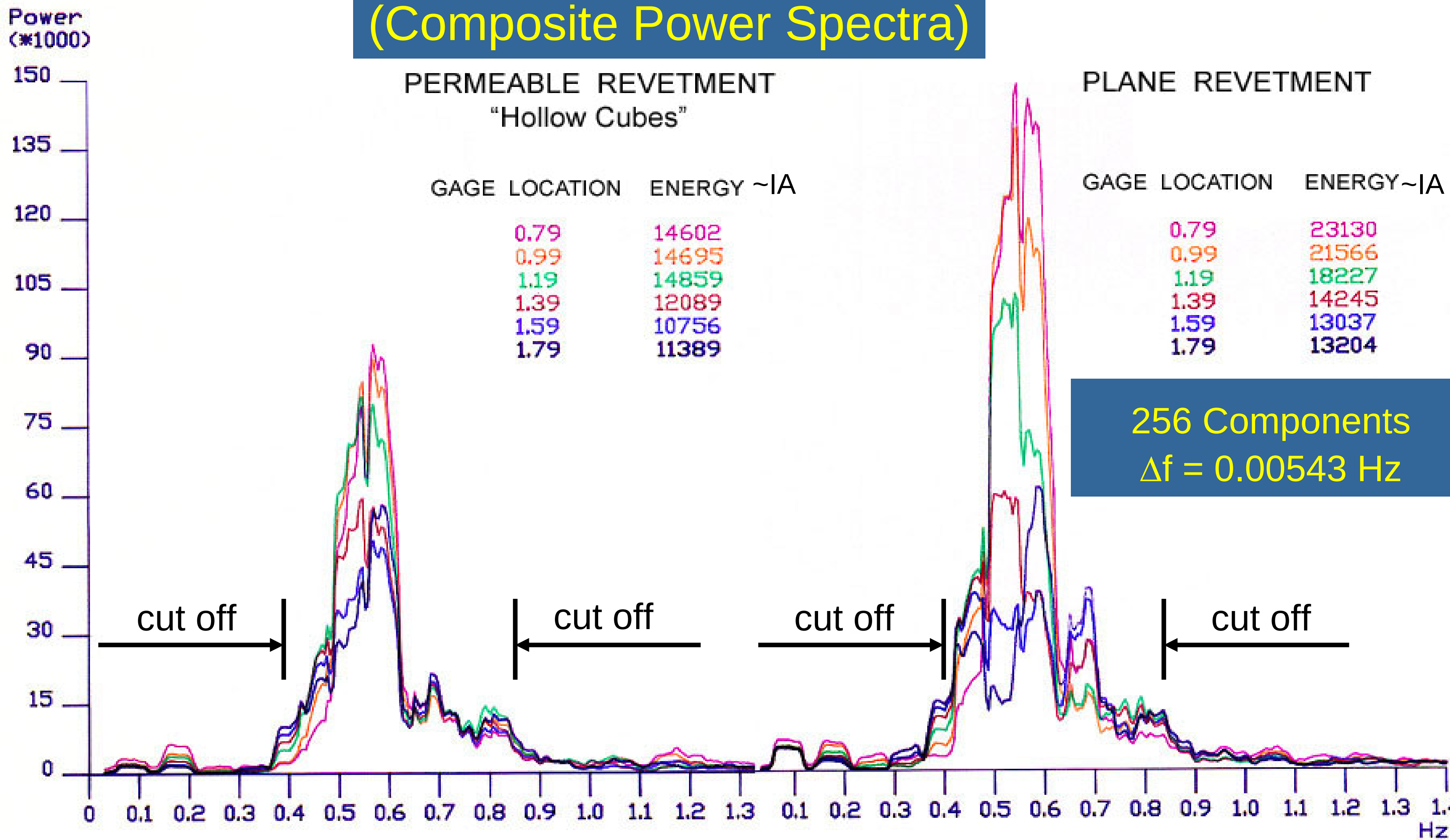
$$\Delta y \approx 0.40m$$

Run down of **collapsing** breaker on **Hollow Cubes**

Run down of **plunging** breaker on **Smooth Slope**

Energy Density Spectra of Water Level Deflections

(Composite Power Spectra)



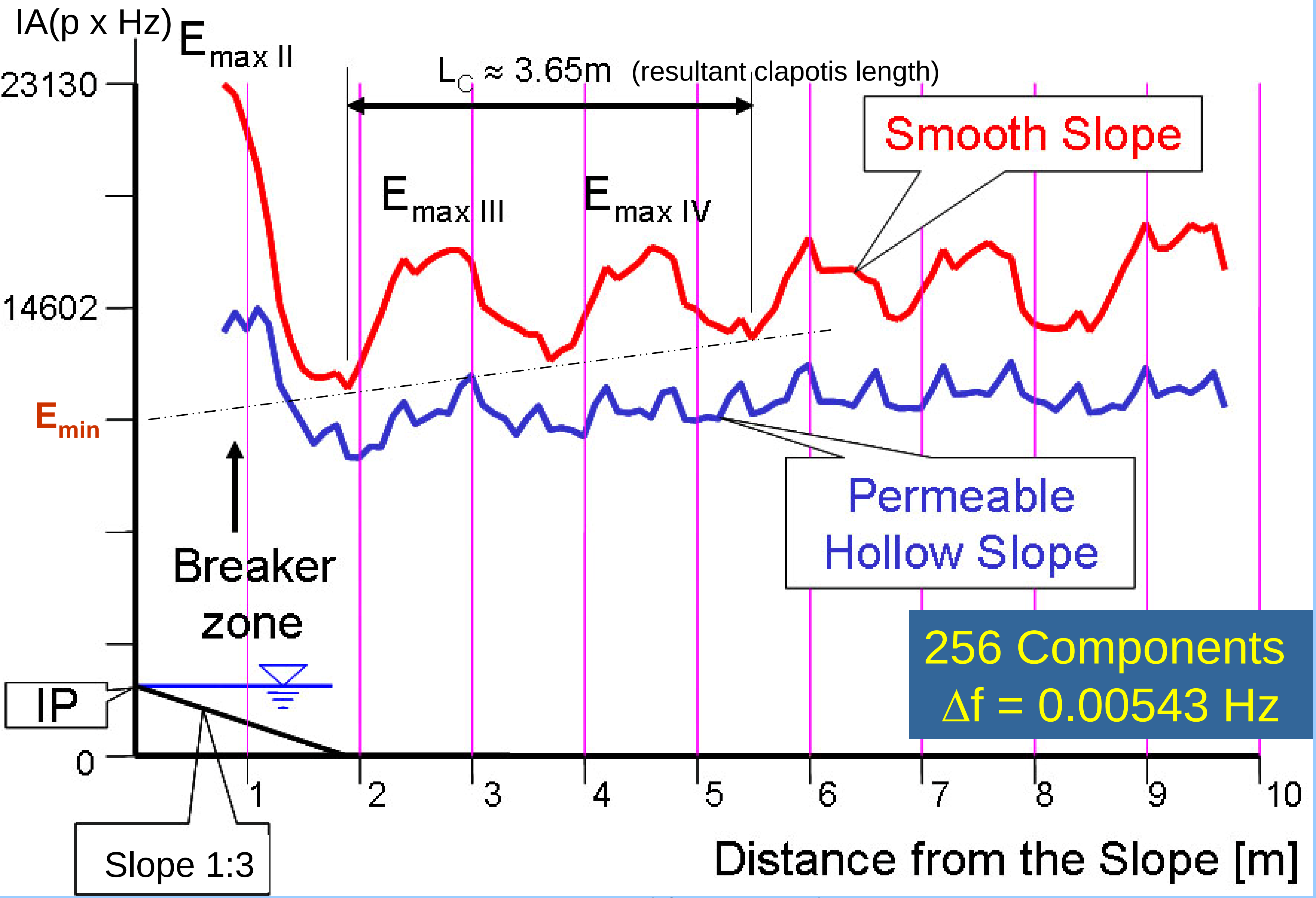
256 Components
$\Delta f = 0.00543$ Hz

Permeable revetment **Plane revetment**

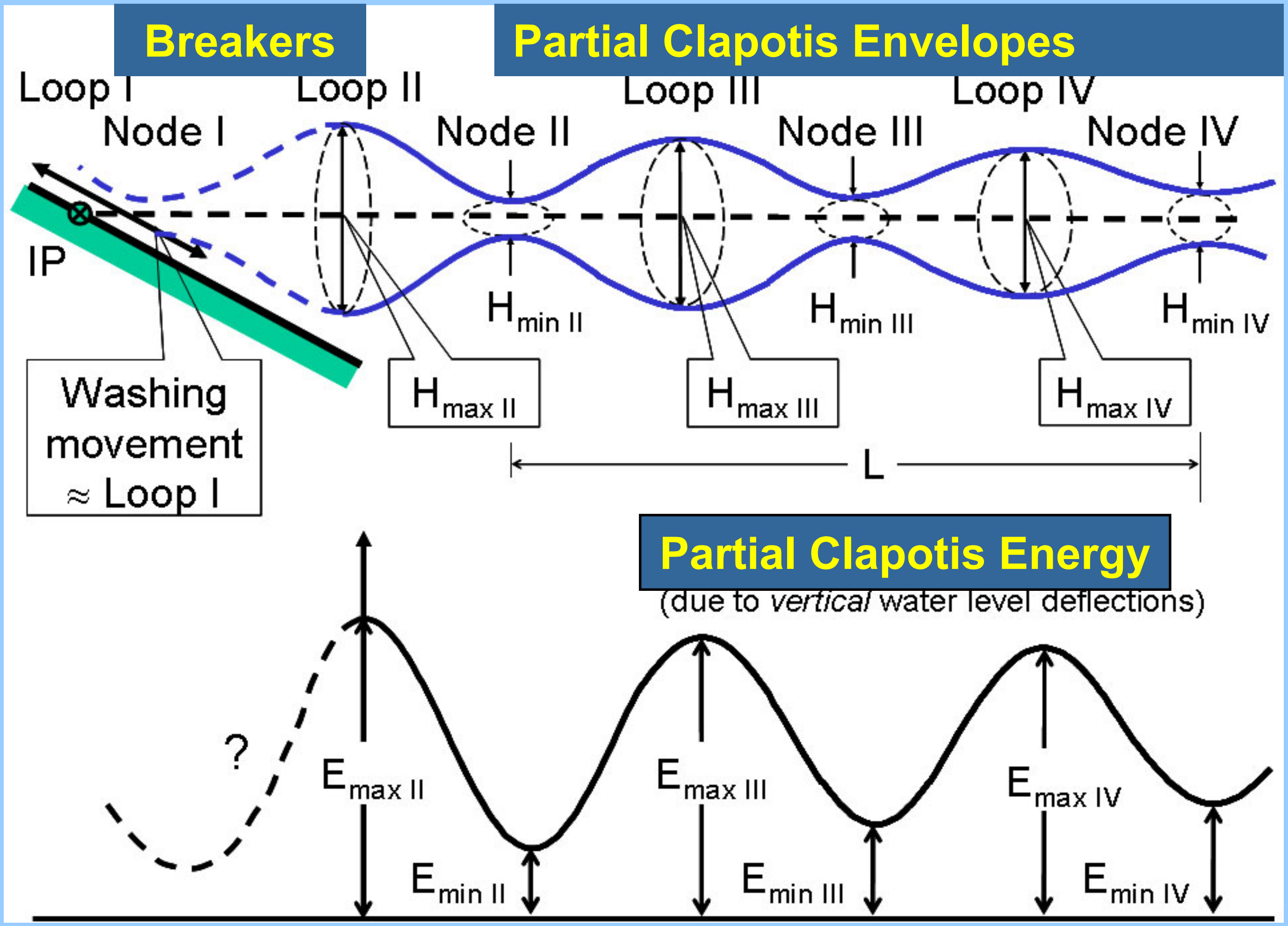
(measured synchronously)

Energy lines resulting from 256 frequency components

total frequency range 0.0326 – 1.3997 Hz



General properties of **partial standing waves** at a slope



Envelopes

Potential energy

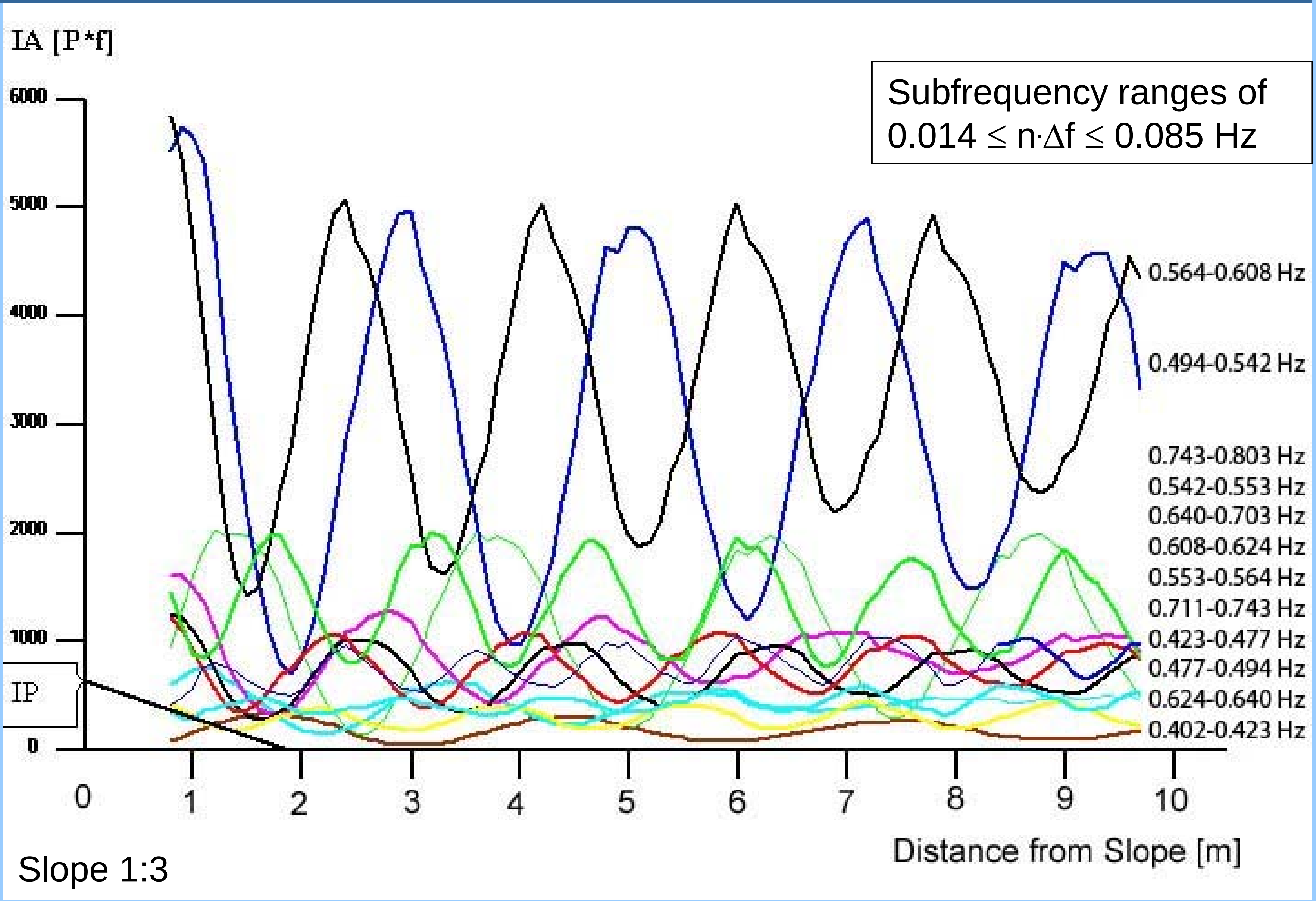
Reflection coefficient

$$C_{r,i} = \frac{\sqrt{E_{\max,i}} - \sqrt{E_{\min,i}}}{\sqrt{E_{\max,i}} + \sqrt{E_{\min,i}}}$$

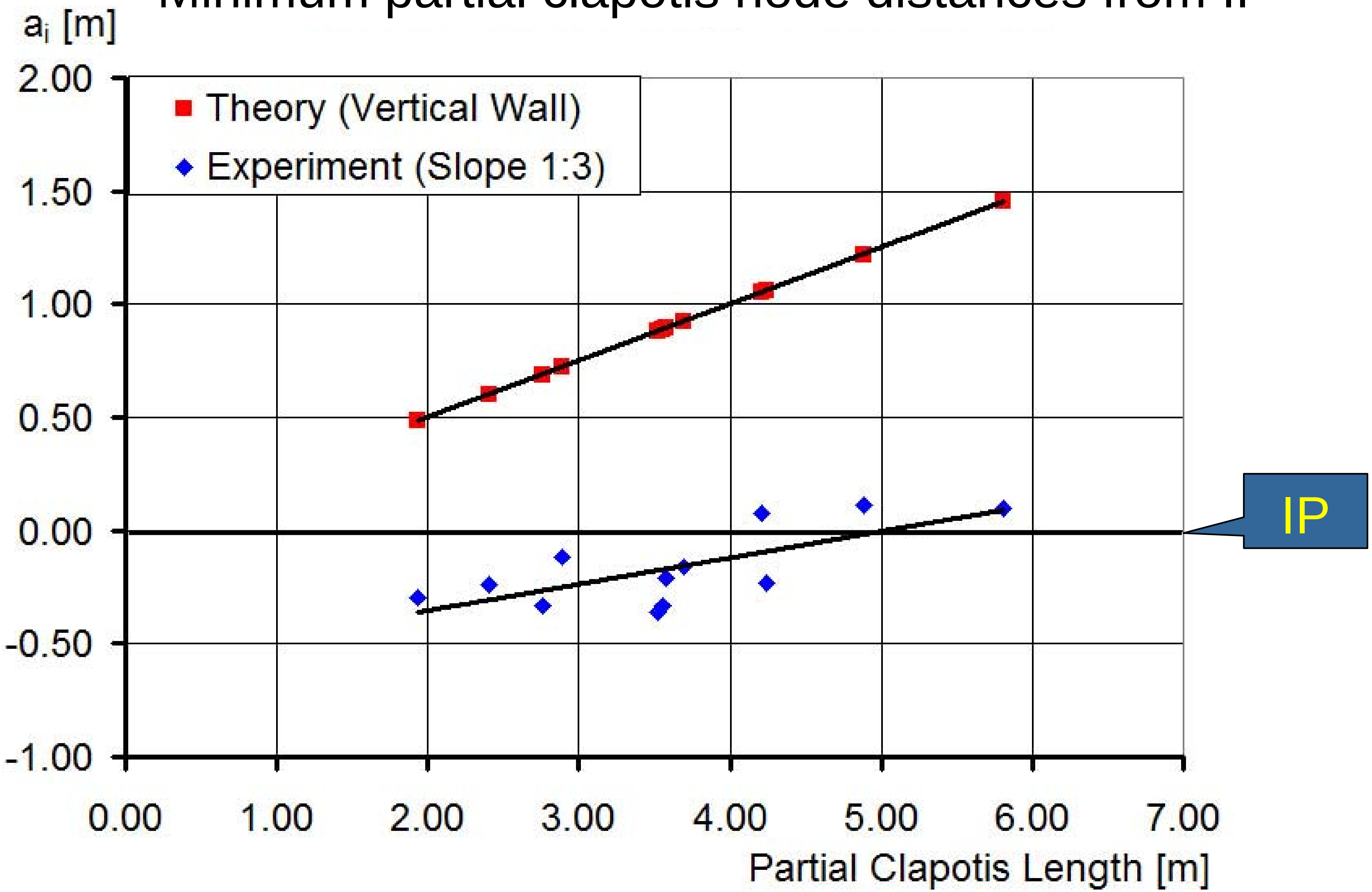
where

$E_{max,i}$ = maximum energy at loop i
and
$E_{min,i}$ = minimum energy at node i

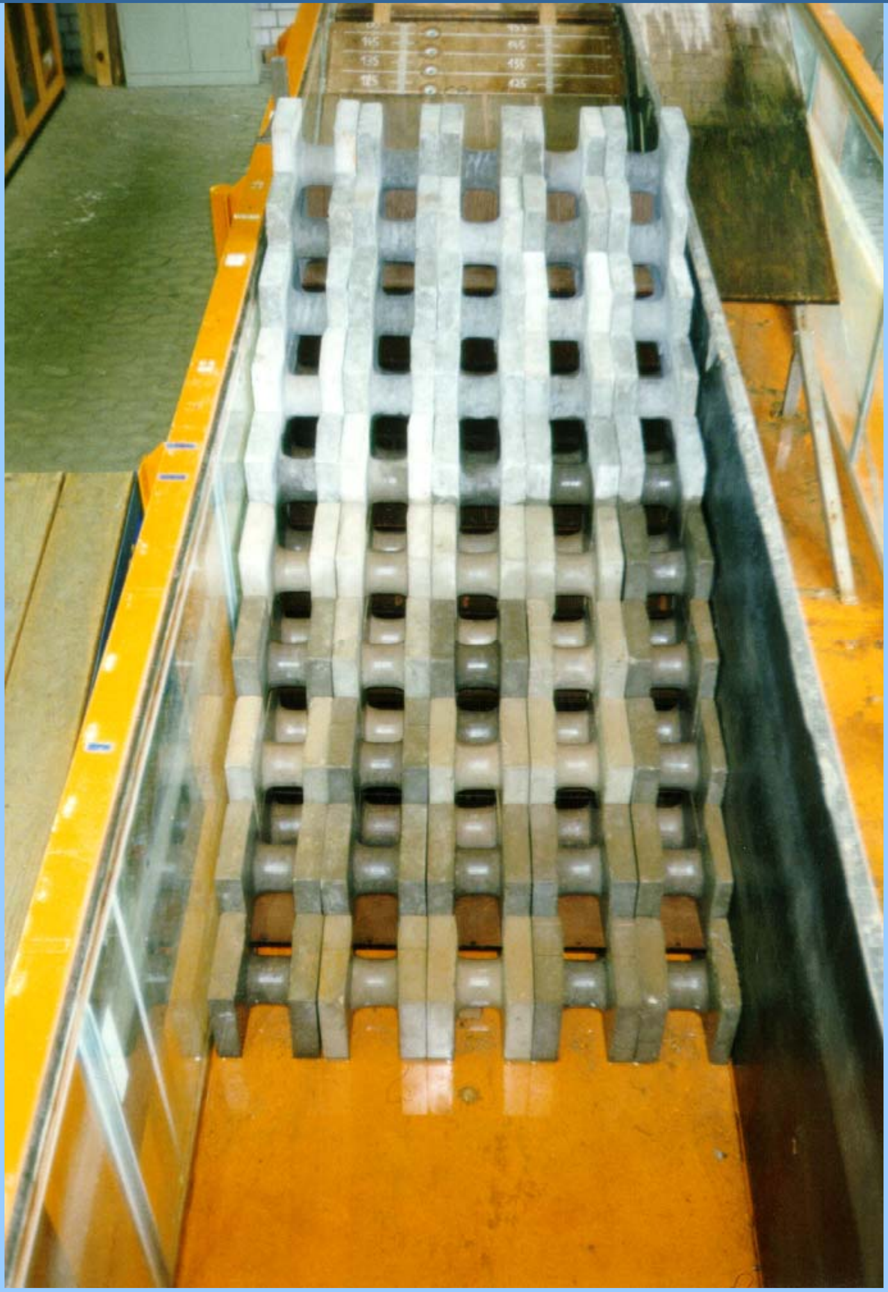
Energy lines of 12 definable partial clapotis waves
frequency range 0.4015 – 0.8030 Hz (74 components)



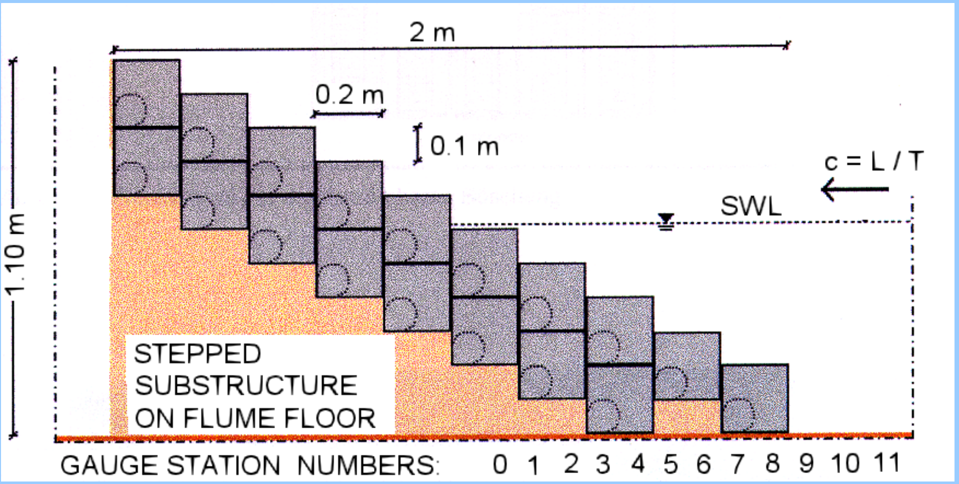
Minimum partial clapotis node distances from IP



Modified data procession and presentation for slopes 1:2



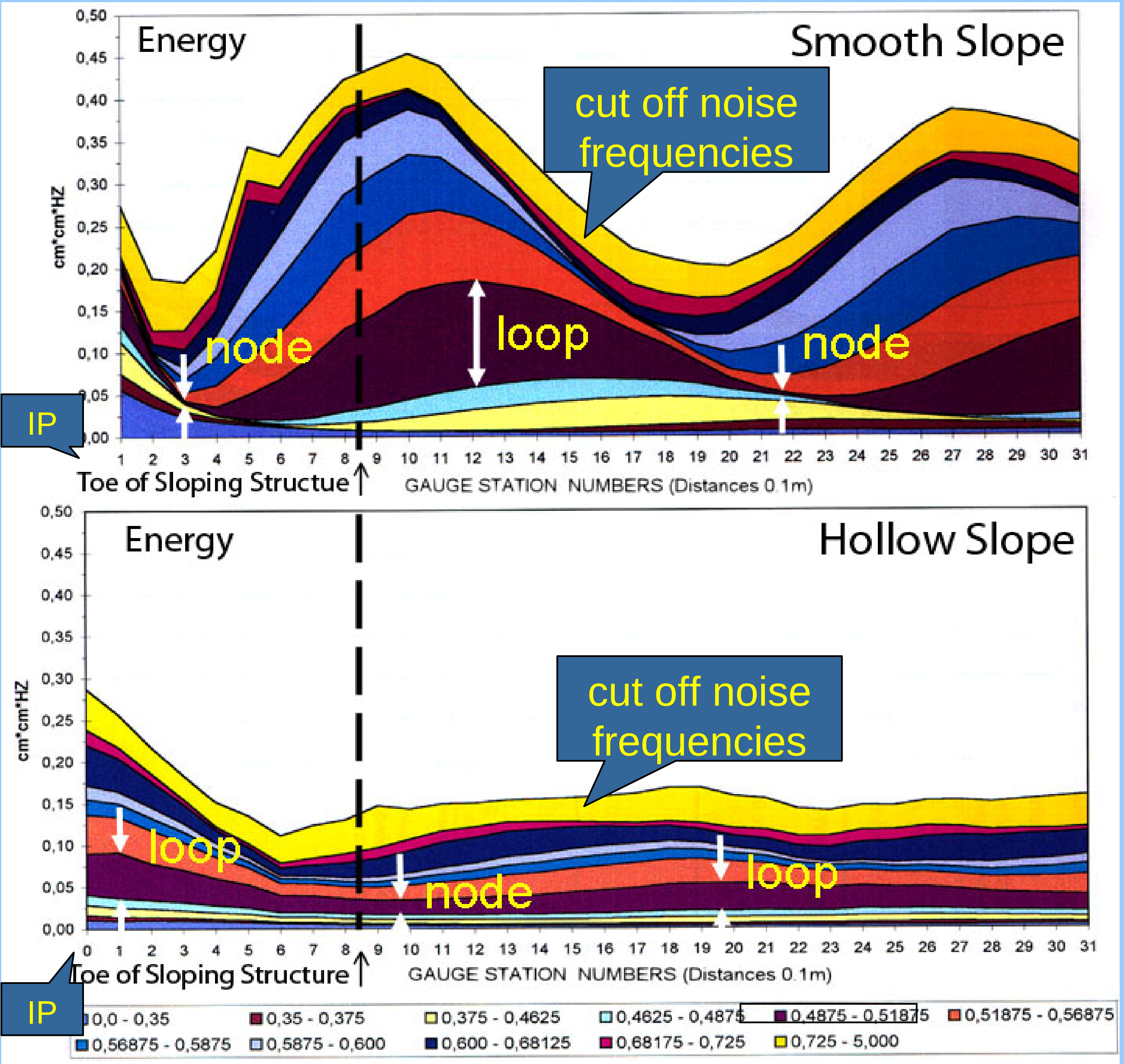
Hollow Cubes piled up to form a **stepped face hollow seawall** structure (2-layer-system).
Slope: 1:2
Model scale: 1:10



Hollow Cubes with the stem placed at one bottom edge

$C_r = +0.2$

Modified data procession and presentation for slopes 1:2



Comments:

- At steeper slope 1:2 measurements closer to IP.

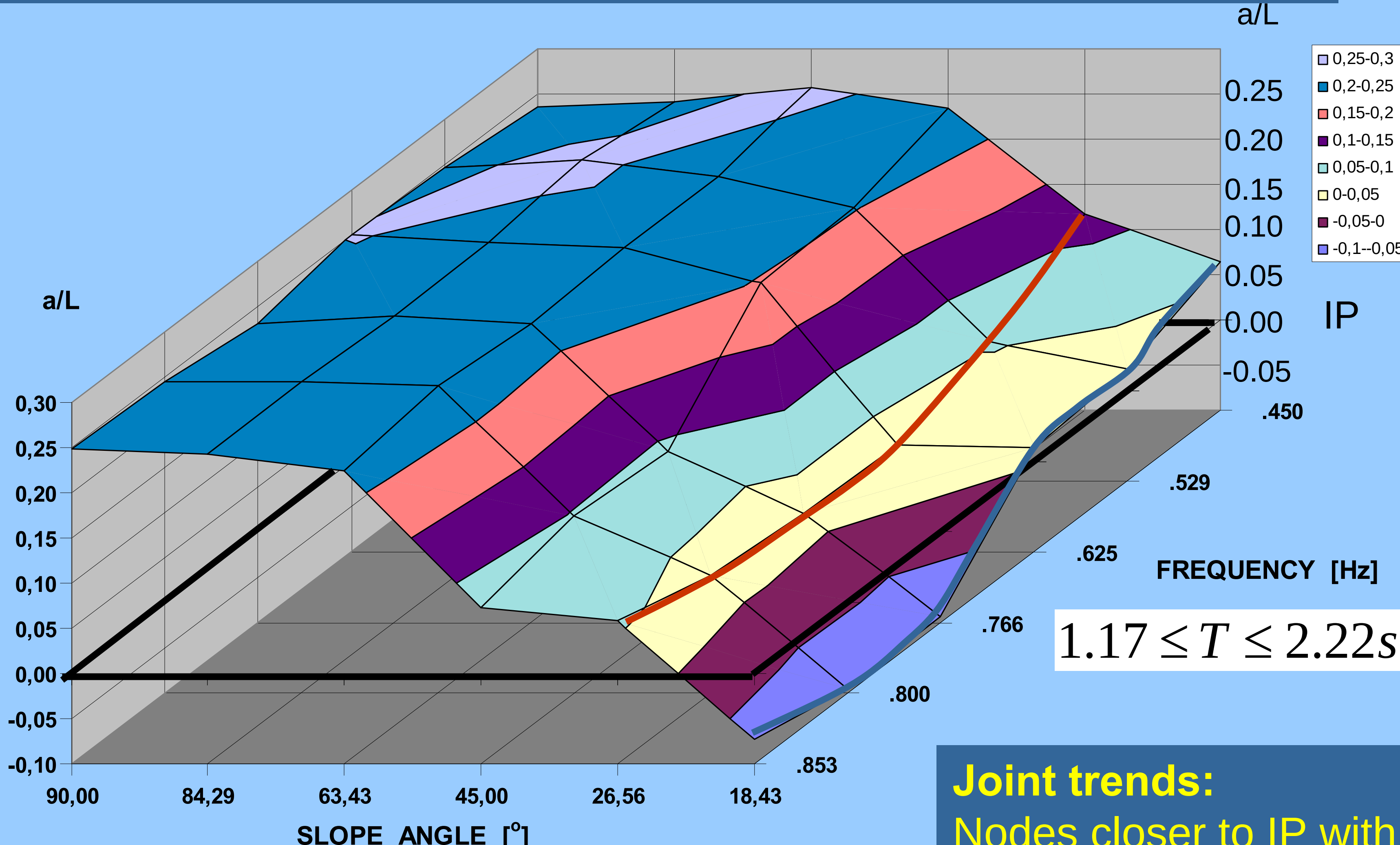
- Set of partial clapotis waves identifiable, although re-reflection effect prevented.

- Energy contents of partial clapotis waves piled up with reference to gauge station numbers

Close to IP

- **nodes** at smooth slope and
- **loops** at hollow slope.

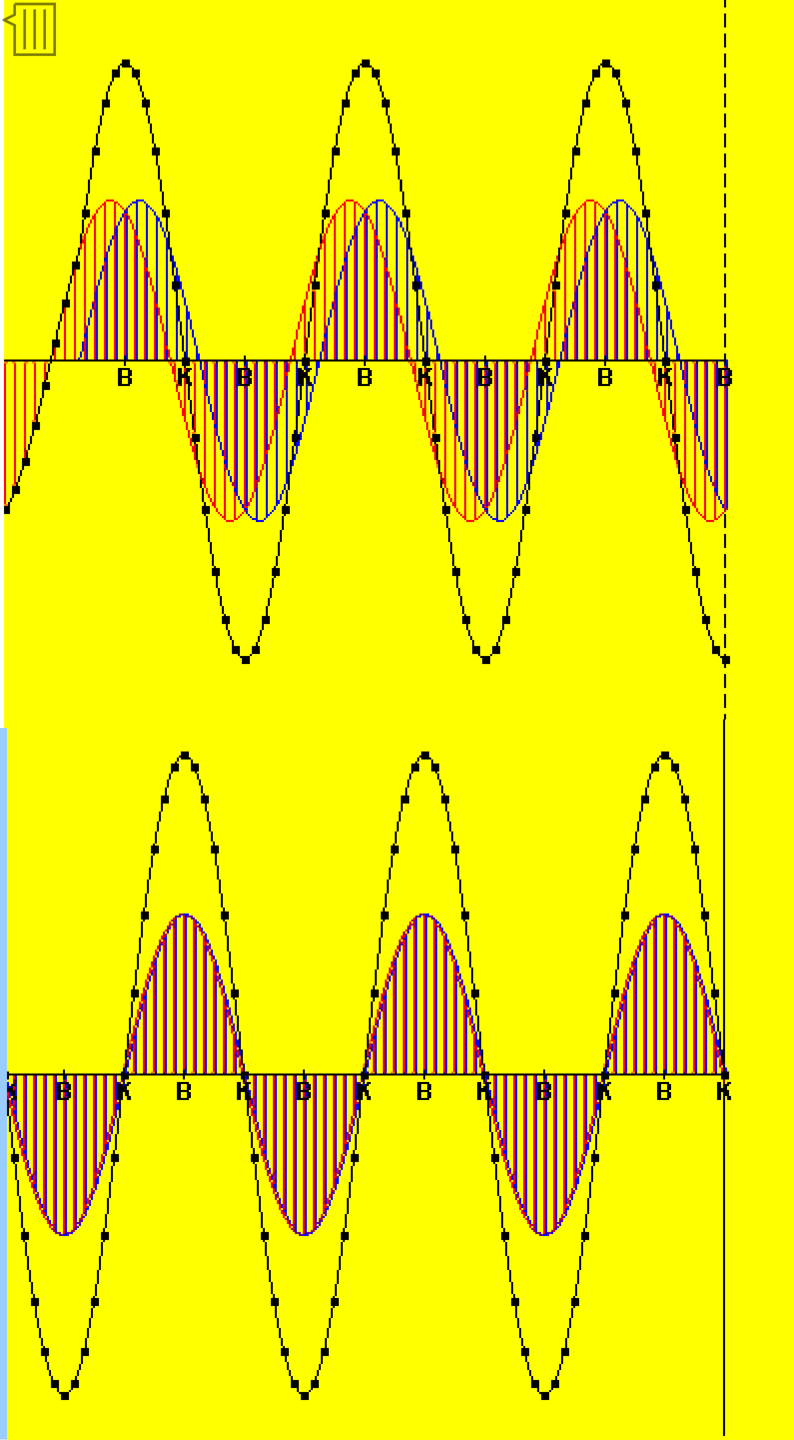
Monochromatic waves at **smooth** slopes:
Relative node distances a/L with reference to slope angle



$$1.17 \leq T \leq 2.22s$$

tanα = 1:m 1:0.1 1:0.5 1:1 1:2 1:3

Joint trends:
Nodes closer to IP with
- slope angle decreasing
- frequency increasing



Two kinds of standing *transversal* waves (without transmission)

Free end reflection without phase jump (shift)
(wave crest reflectet by wave crest)

Known examples:
- Rope waves
- Electromagnetic waves
- Water waves (Clapotis)

Fixed end reflection with phase jump $\Delta\varphi = 180^o$
(wave crest reflectet by wave trough & vice versa)

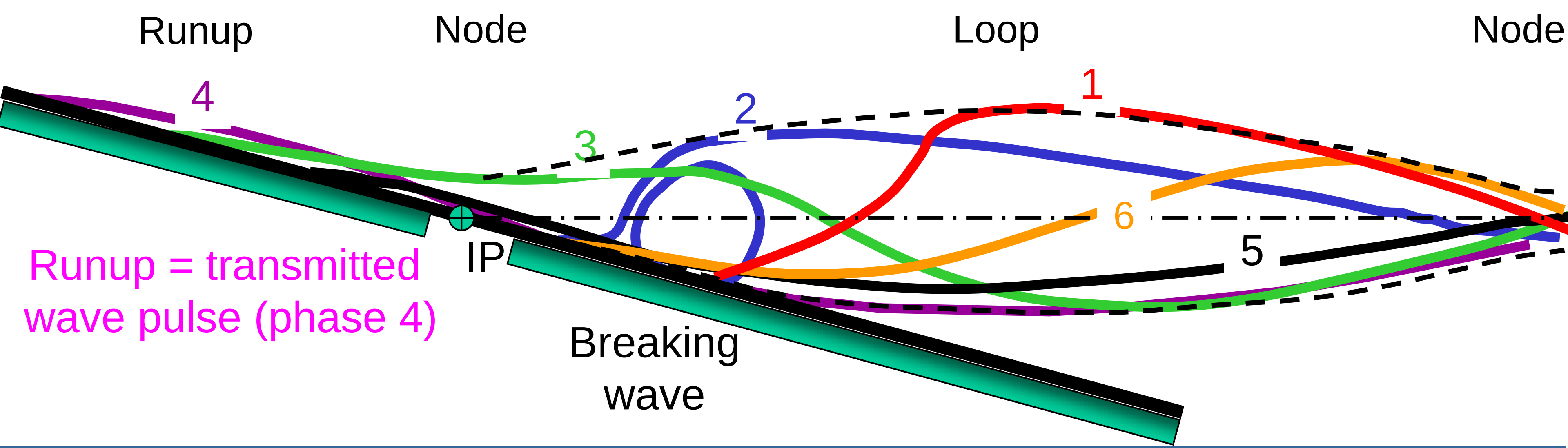
Known examples:
- Rope waves
- Electromagnetic waves
- Water waves (at a slope?)

incident wave: red reflected wave: blue
resultant wave: black

Click on the figure to start animation

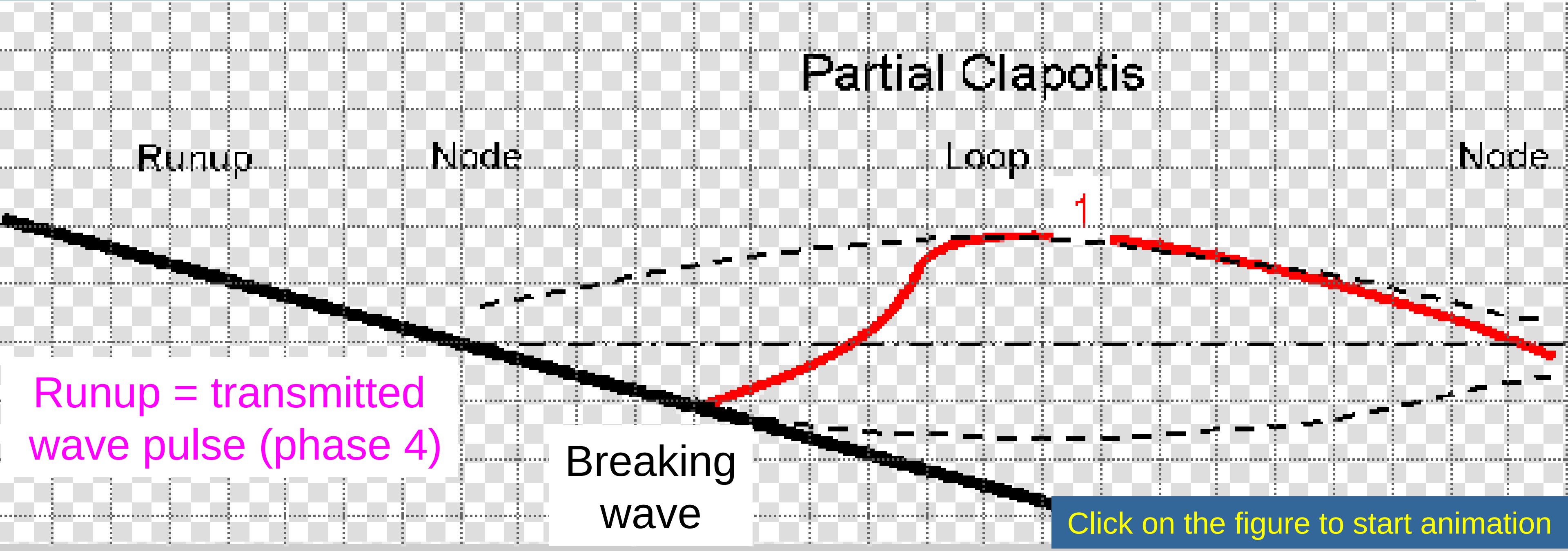
Animations after Walter Fendt (2003)
http://www.walter-fendt.de/ph14d/stwellerefl.htm

Wave *breaking* combined with partial *reflection* and *transmission* (wave moving to the left)



- The existence of a **node close to the slope** provides evidence of ***partial* reflection <u>with</u> a phase jump**.
- Note opposite transmitted and reflected deflections around IP.
- **Conservation of momentum:**
  Smaller & slower transmitted wave pulse $\mathbf{c_t < c_i}$ combined with **negative reflection** (wave crest reflected by wave trough & vv)

Wave *breaking* combined with partial *reflection* and *transmission* (wave *moving* to the left)



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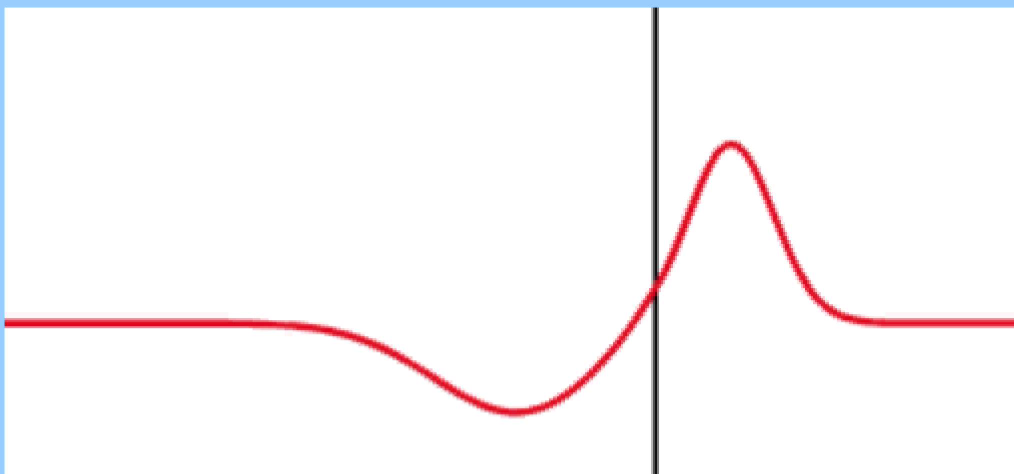
Analogue from light waves: Fresnel´s Equations describing *reflection and transmission* of light at uniform planar interfaces

Interface of two refractive index media

lower ↓ higher



c_i → ← c_r → $c_t < c_i$

breaking wave

Incident and reflected pulse respectively

transmitted pulse = runup

negative partial reflection

Partial **reflection and transmission** of a pulse travelling to the right from **low to high** refractive index medium.

Superimposition of positive incident and negative reflected pulses **not** shown !

Animation after Oleg Alexandrow (2007)
http://de.wikipedia.org/wiki/Datei/:Partial_transmittance.gif

Click on the figure to start animation

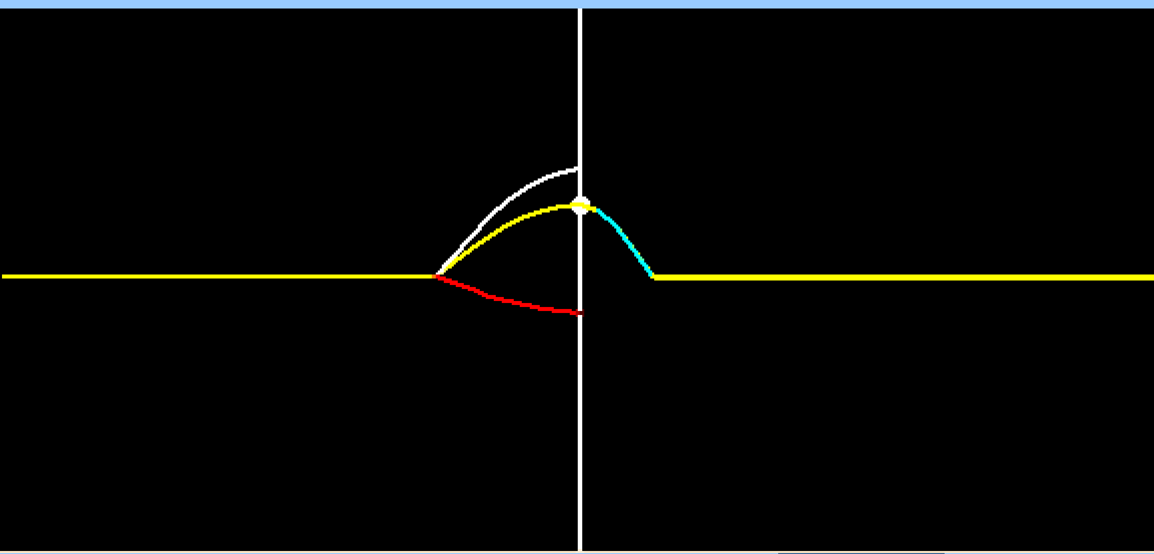
Analogue behaviour of water waves breaking on a slope (except rundown).

Analogue from rope waves:

Partial **reflection and transmission** of a puls travelling to the right from **thinner to thicker** rope diameter.

Boundary of two ropes

thinner ↓ thicker



$c_r = c_i$ → ←   → $c_t < c_i$

breaking wave

incident and reflected pulse respectively

transmitted pulse = runup

negative partial reflection

incident pulse: white
reflected pulse: red
transmitted pulse: blue

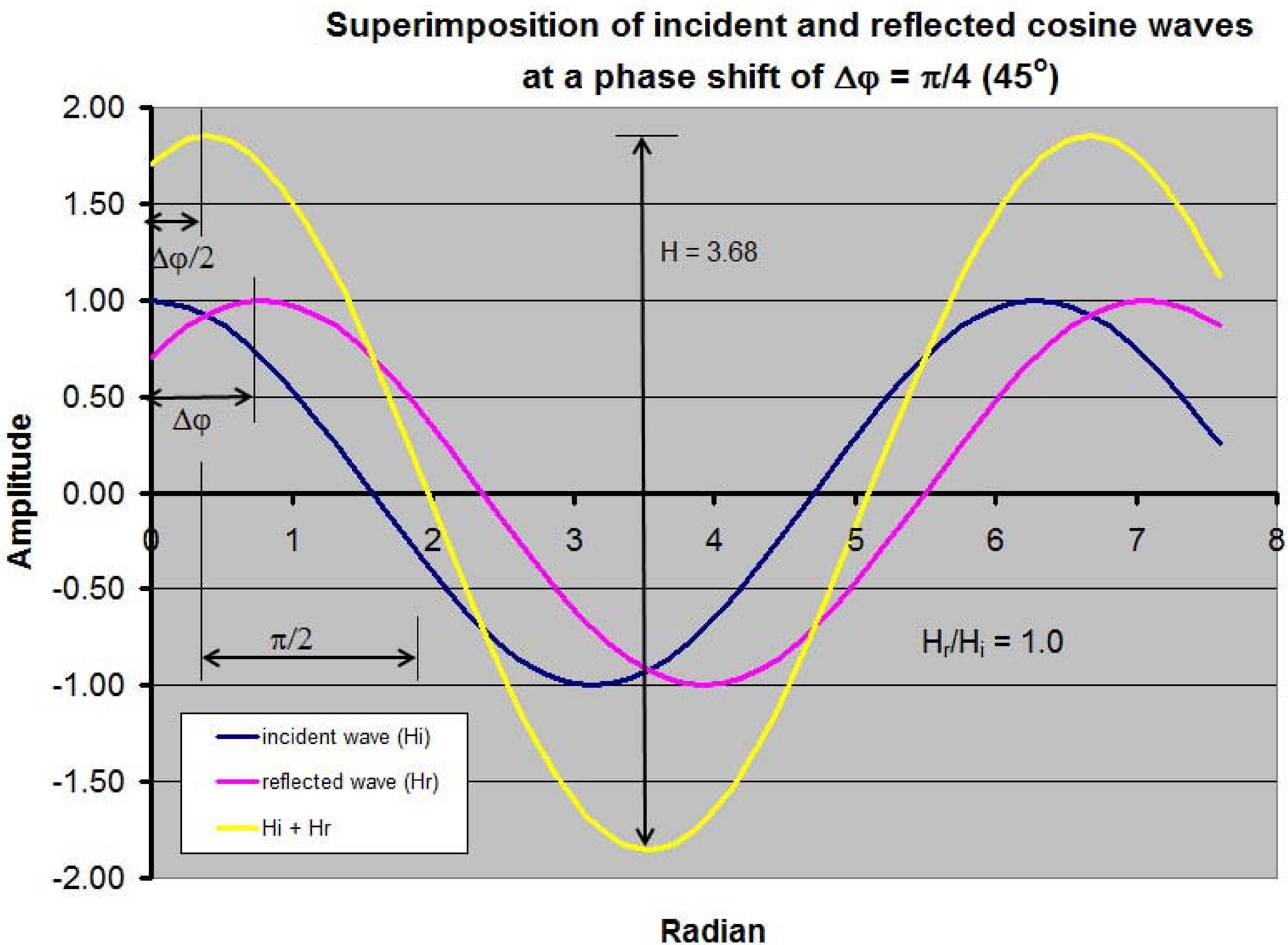
Superimposition of positive incident and negative reflected pulse **not** shown !

Animations after B. Surendranath Reddy (2004)
http://www.surendranath.org/Apps.html

Click on the figure to start animation

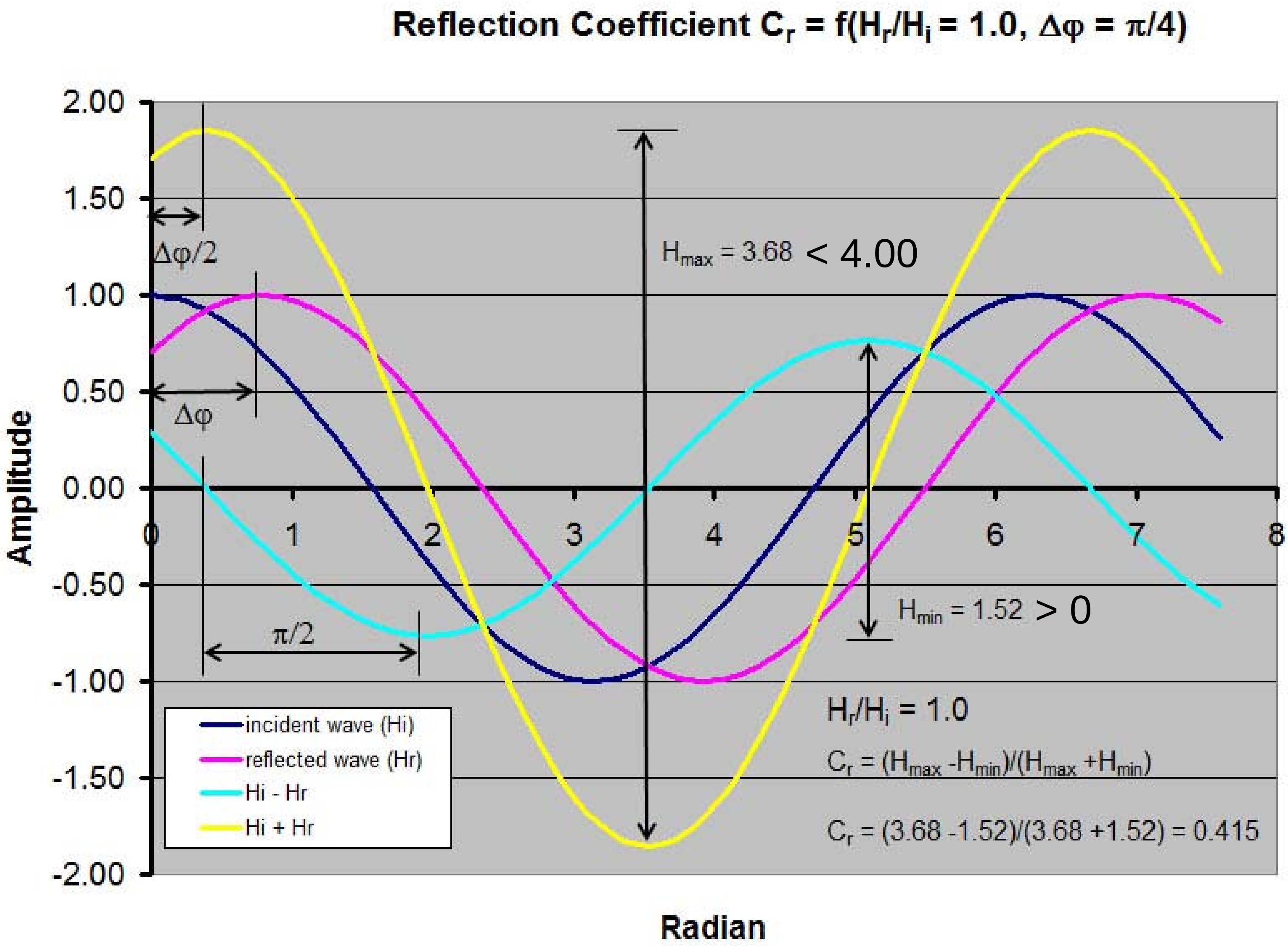
Analogue behaviour of water waves breaking on a slope (except rundown).

Further considerations on the positioning of partial standing waves with reference to a sloping structure



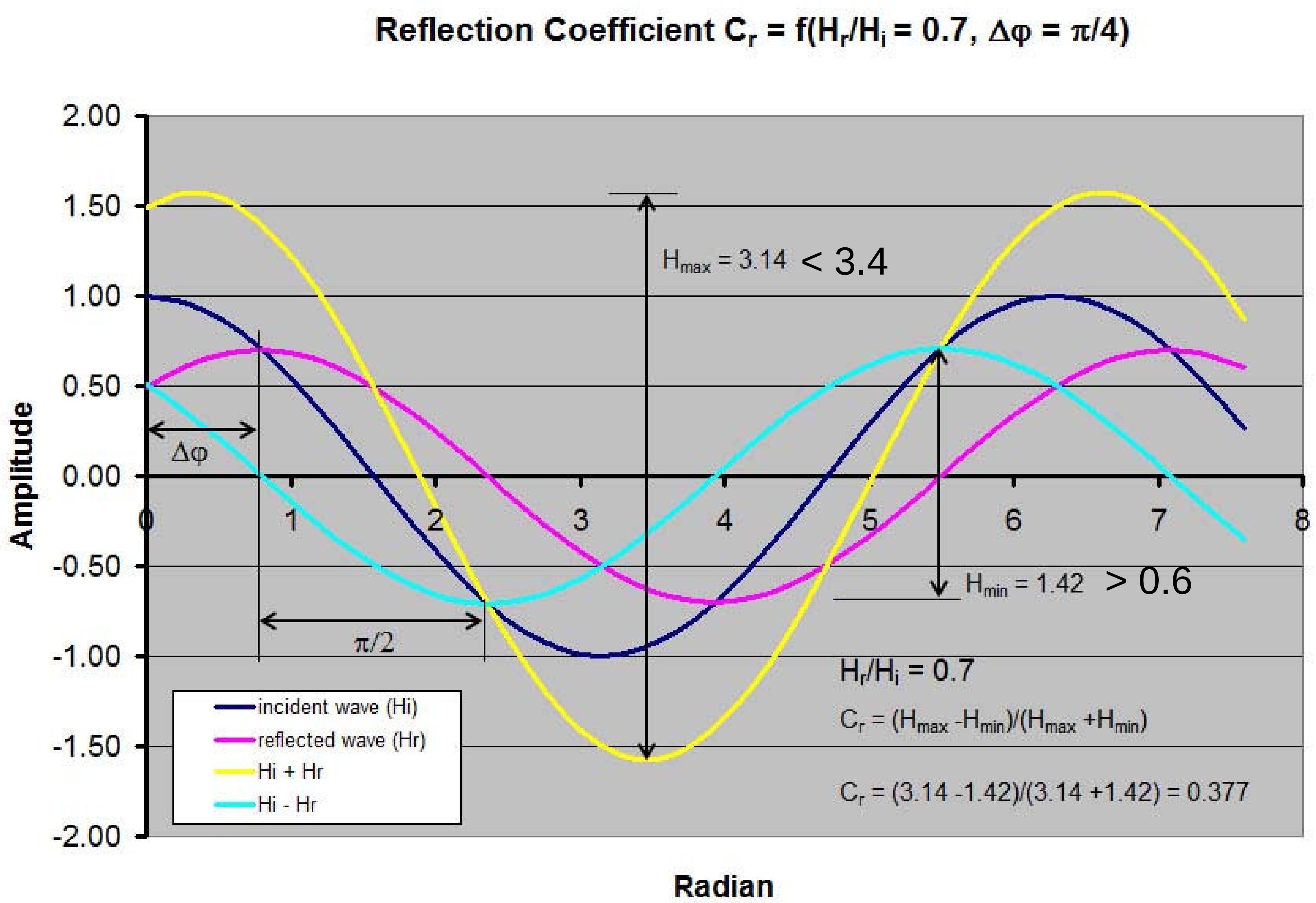
Consequences of phase shifts on reflection coefficients

Wave height ratio: $H_r / H_i = 1.0$



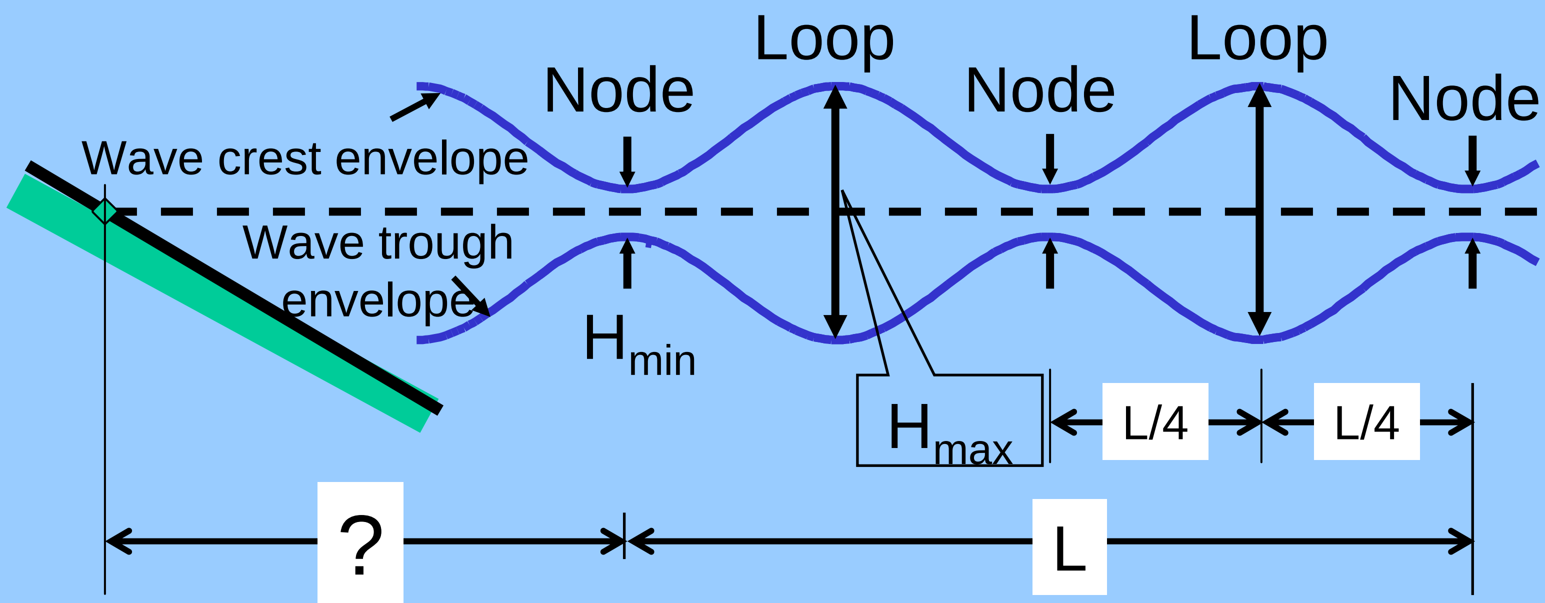
Consequences of phase shifts on reflection coefficients

Wave height ratio: H_r / H_i = 0.7



Consequences of a phase shift on reflection coefficients

Partial Clapotis Envelopes



Reflection Coefficient (by Healy, 1953):

Wave height ratio

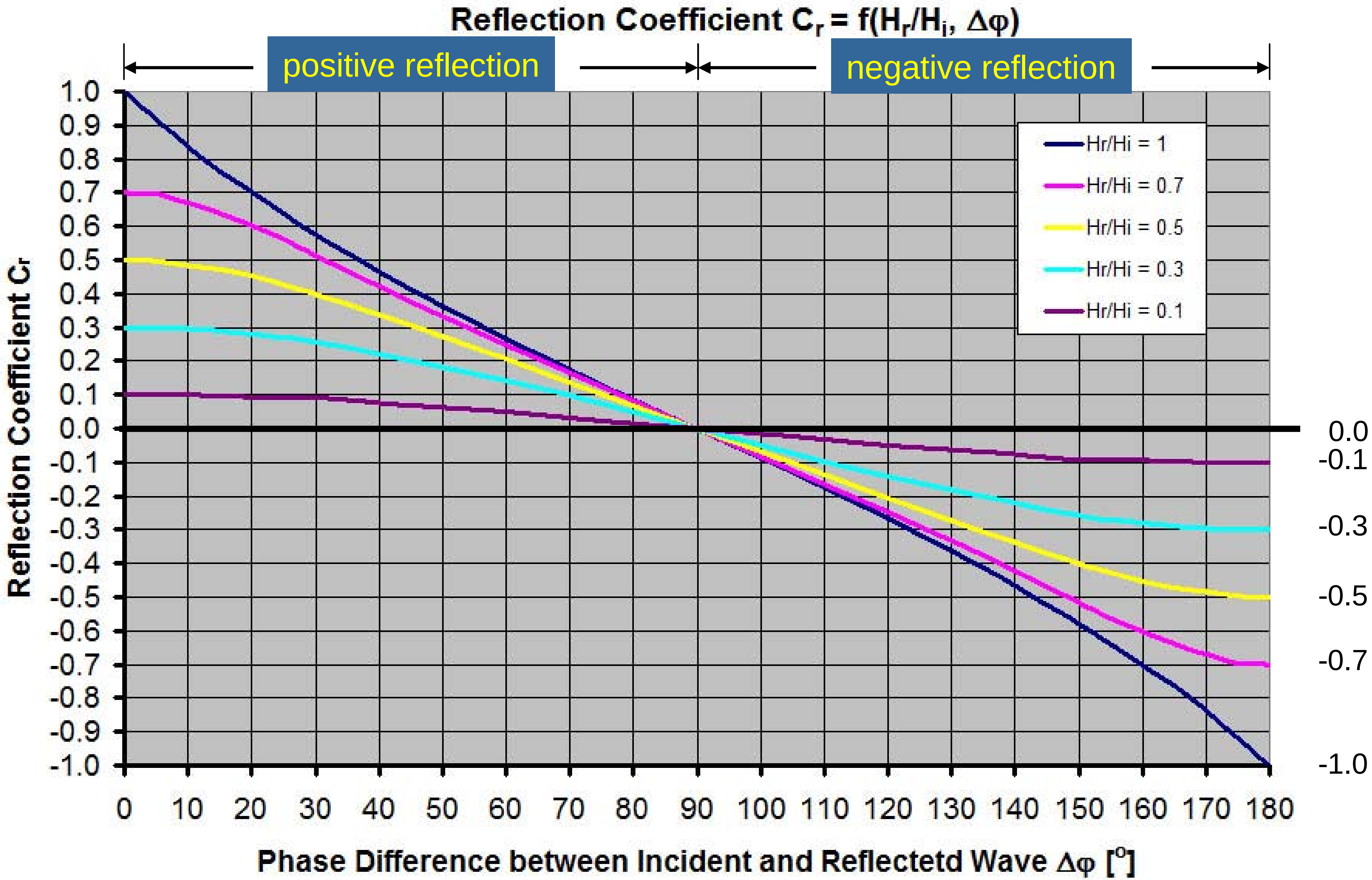
$$C_r = \frac{H_r}{H_i} = \frac{H_{\max} - H_{\min}}{H_{\max} + H_{\min}}$$ where $$H_{\max} = H_i + H_r$$ and $$H_{\min} = H_i - H_r$$

Phase shift considered

$$C_r = f\left(\frac{H_r}{H_i} = 0.7, \Delta\varphi = \frac{\pi}{4}\right) = \frac{H_{\max} - H_{\min}}{H_{\max} + H_{\min}} = \frac{3.14 - 1.42}{3.14 + 1.42} = 0.377$$

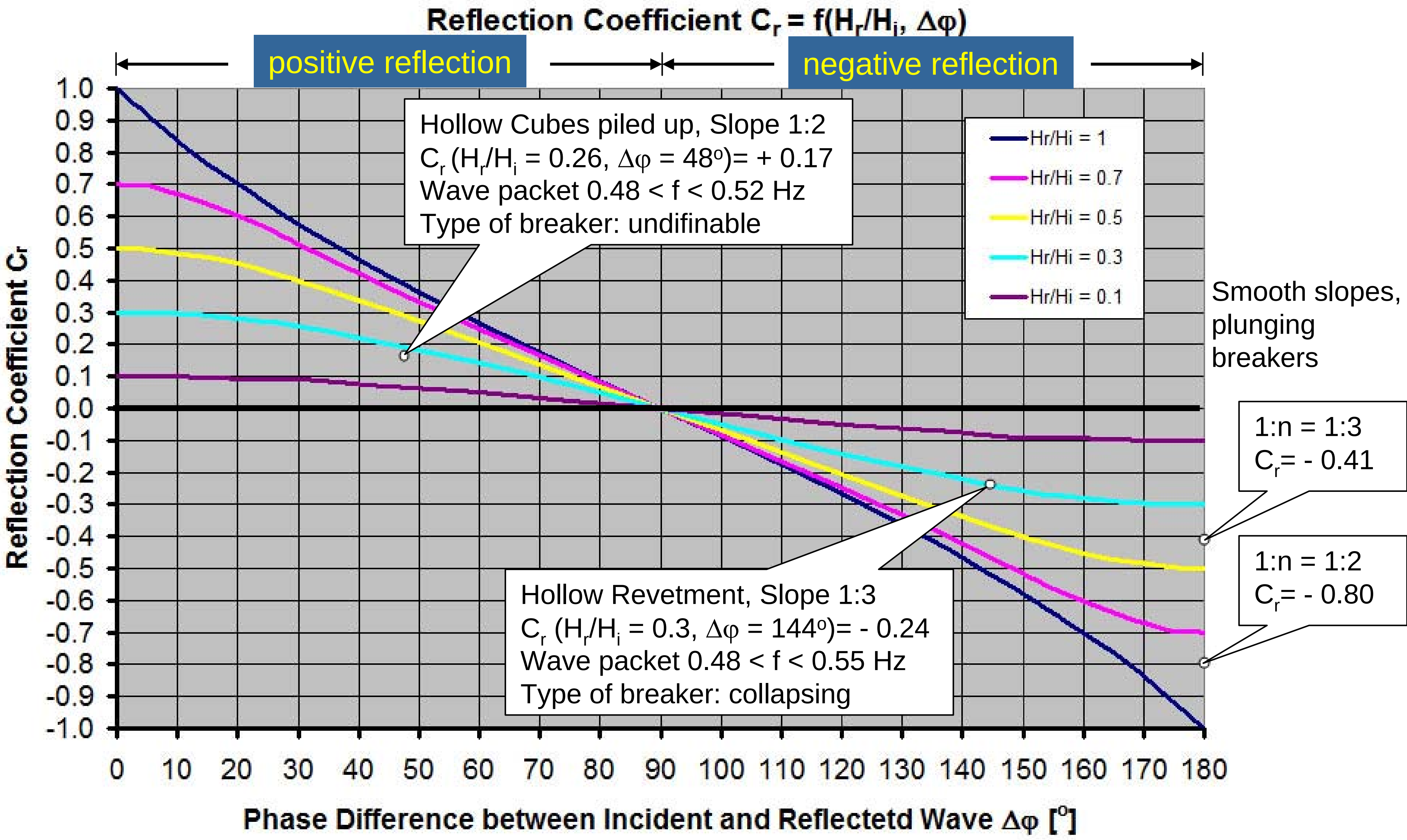
Reflection coefficients in the range of parameters

$0.1 \leq H_r / H_i \leq 1.0$ and phase distances $0° \leq \Delta\varphi \leq 180°$



Found reflection coefficients attached to parameters

$0.1 \leq H_r / H_i \leq 1.0$ and phase distances $0° \leq \Delta\varphi \leq 180°$



Trivial suggestions on the **joint effect of reflection, transmission and dissipation** of breaking waves at a slope

- Verify current findings in a **natural** scale:
  Specify phase shifts for **longer waves** and **less inclined** slopes.

- Include the phase difference $\Delta\varphi$ in the presentations of reflection coefficients and of types of breakers **in addition** to the **Iribarren** nr IR $\xi = \tan\alpha / \sqrt{s}$

- Standardize the application of composite response spectra, in order to obtain **spectral coefficients of reflection, transmission and absorption.**

Extended version: http://nbn-resolving.de/urn:nbn:de:0066-201008270