ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

Rock Armor Damage in Depth-limited Breaking Wave Conditions

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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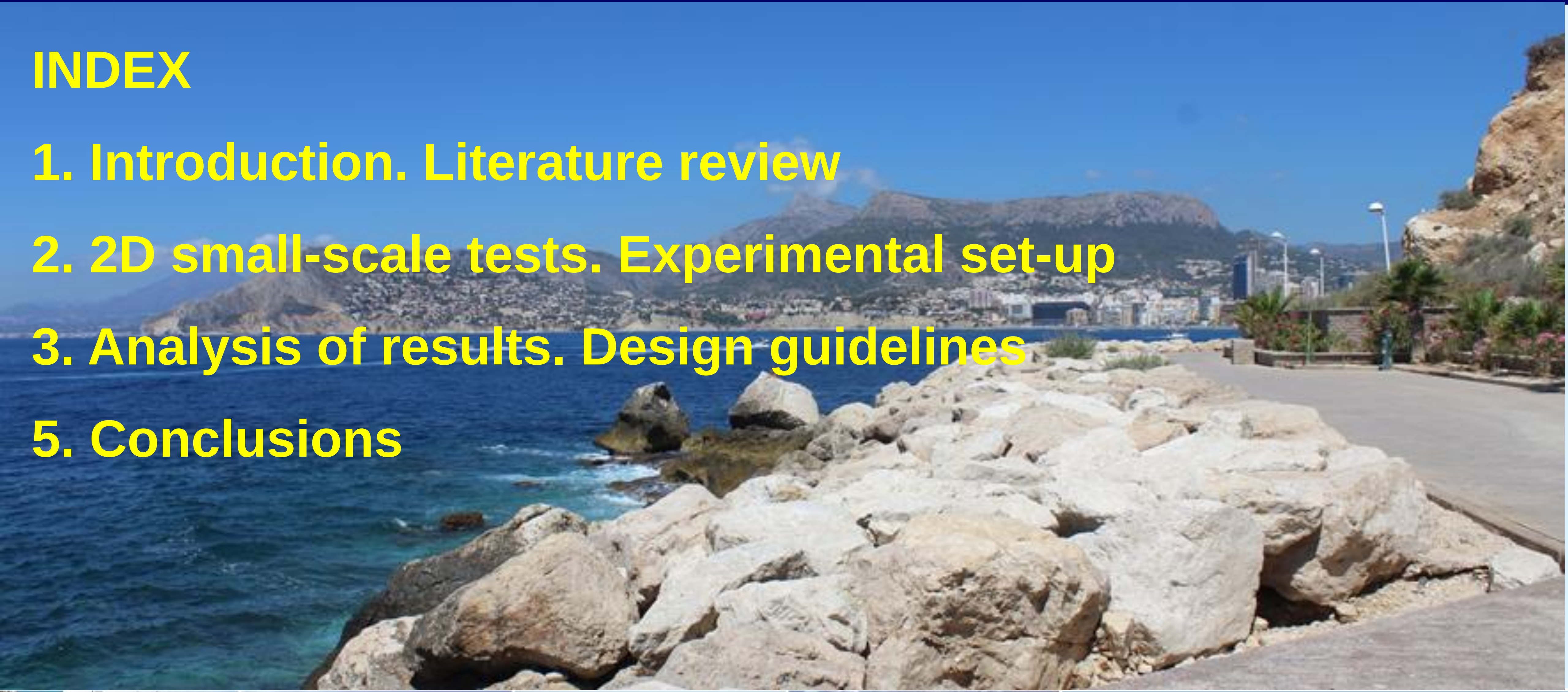

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2. 2D small-scale tests. Experimental set-up

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MOUND BREAKWATERS: HYDRAULIC STABILITY OF ARMORS

Design formulas derived from **physical tests in non-breaking wave conditions**

Rayleigh distribution: $H_{2\%} \approx 1.4\ H_s$

Most **structures are built** in depth-limited **breaking wave conditions**

Nonlinear and **highest waves break before reaching the structure: $H_{2\%} < 1.4\ H_s$**

$$N_s = \frac{H}{\Delta D_{n50}} = (K_D \cot\alpha)^{1/3}$$

breaking wave conditions: $H = H_b$

K_D=3.5 (USACE, 1975) and **K_D=2.0** (USACE, 1984) **IMPLICIT SAFETY FACTORS?**

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1. Design wave height (intermediate-depth)

breaker index method

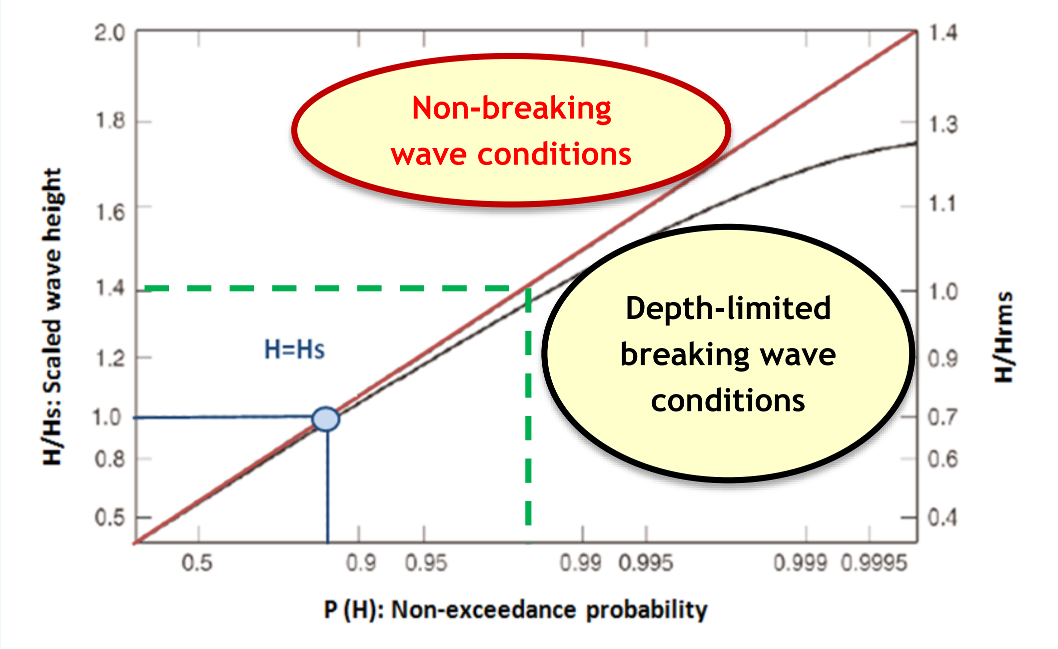
Goda (1974, 2000 and 2012)

$$H_{1/3} = \begin{cases} (K_S H_0') & \textit{for } h/L_0 \geq 0.2 \\ \min[(\beta_0 H_0' + \beta_1 h), (\beta_{max} H_0'), (K_S H_0')] & \textit{for } h/L_0 < 0.2 \end{cases}$$

$$H_{max} = H_{1/250} = \begin{cases} (1.8 K_S H_0') & \textit{for } h/L_0 \geq 0.2 \\ \min[(\beta_0 * H_0' + \beta_1 * h), (\beta_{max} * H_0'), (1.8 K_S H_0')] & \textit{for } h/L_0 < 0.2 \end{cases}$$

2. Shallow foreshore: Wave height distribution

Battjes and Groenendijk (2000)



Composite Weibull Distribution (CWD)

$$F(H) = \begin{cases} 1 - \exp\left[-(H/H_1)^{k_1}\right] & : H \leq H_{tr} \\ 1 - \exp\left[-(H/H_2)^{k_2}\right] & : H \geq H_{tr} \end{cases}$$

Numerical simulations (**SwanOne**)

Incident $\{H_{m0}, T_p\}$ ➡ **H_{m0}, $H_{1/10}$, $H_{2\%}$ (CWD)**

wave generation zone (deep water) — wave breaking zone (shallow water)

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USACE (1975, 1984): $N_s = \frac{H}{\Delta D_{n50}} = (K_D \cot\alpha)^{1/3} \quad \{S^{0.2}\}$ **H$_b$** non-breaking + regular

Van der Meer (1988): $N_s = \frac{H_s}{\Delta D_{n50}} = S^{0.2} \cdot (\max[f_1(Ir, P, N); f_2(Ir, P, N, \cot\alpha)])$

H$_s$ ➡ **H$_{2\%}$/1.4** <5% tests in breaking wave conditions (m=1/30 and $\cot\alpha$ =2.0)

<u>tests in breaking wave conditions</u>

Melby and Kobayashi (1998): **H$_s$**

$$S(t) = S(t_n) + 0.025\left(\frac{H_s}{\Delta D_{n50}}\right)_n^5 \frac{\left(t^{0.25} - t_n^{0.25}\right)}{(T_m)_n^{0.25}}$$

S=k N$_s$^{5}

(m=1/20 and $\cot\alpha$ =2.0)

Van Gent et al. (2003): **H$_{2\%}$**

$$\frac{H_{2\%}}{\Delta D_{n50}} = c_{pl} S^{0.2} P^{0.18} N_z^{-0.1} \xi_{s-1}^{-0.5} \qquad \text{(Plunging)}$$

$$\frac{H_{2\%}}{\Delta D_{n50}} = c_s S^{0.2} P^{-0.13} N_z^{-0.1} (\cot\alpha)^{0.5} \xi_{s-1}^{P} \qquad \text{(Surging)}$$

measurement?
H$_s$, H$_{2\%}$?

(m=1/30 and 1/100)

($\cot\alpha$ =2.0 and 4.0)

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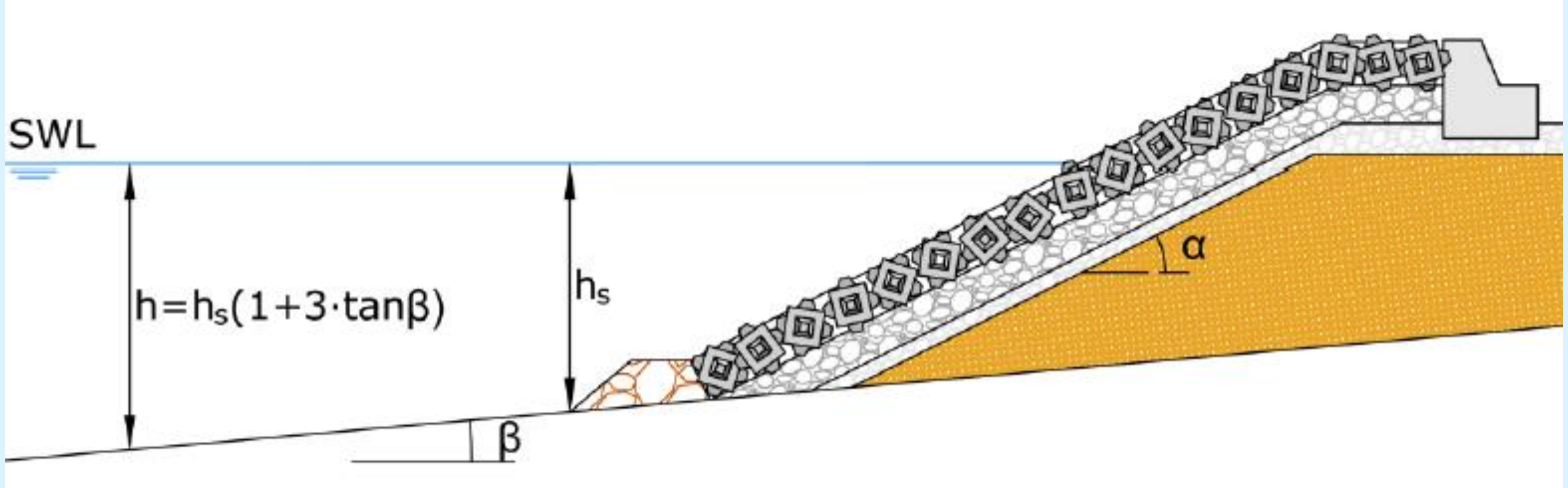
SINGLE- AND DOUBLE-LAYER ARMORS

$$N_s = \frac{H}{\Delta D_{n50}} = (K_D \cot\alpha)^{1/3}$$ (Hudson formula for preliminary design)

USACE (1975 and 1984): K_D(breaking) < K_D(non-breaking) — higher safety factor?

Xbloc® (2014): K_D(non-breaking) < K_D(breaking) — depth-limited H_{max}?

CLI (2018): K_D(breaking) < K_D(non-breaking) — higher safety factor?



bottom slope → hydraulic stability

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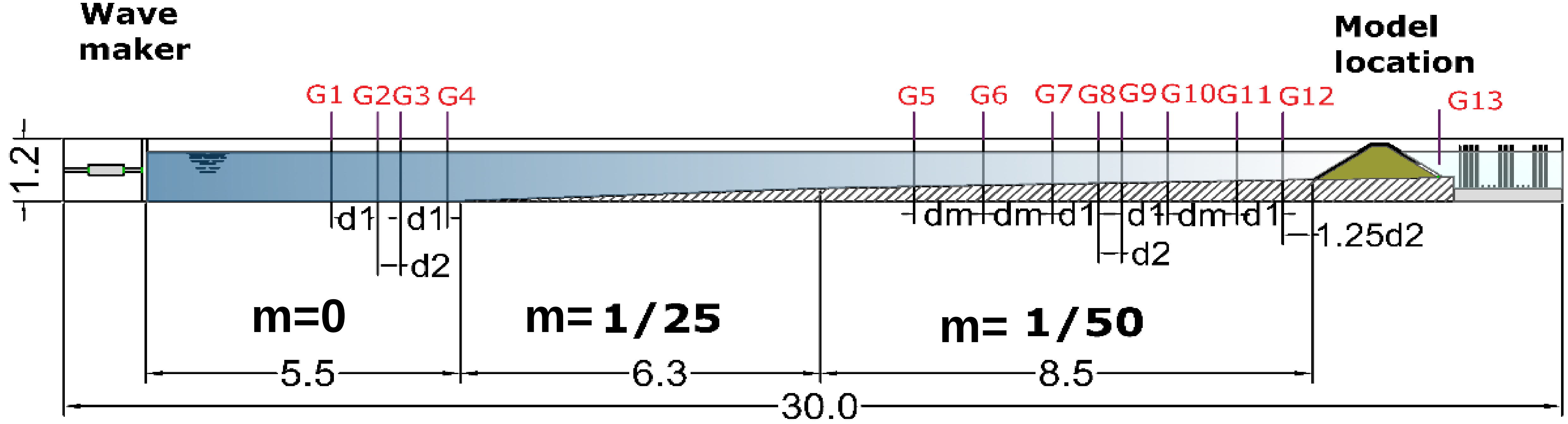
LPC-UPV wave flume (30x1.2x1.2 meters), bottom slope m=1/50



d1=80 cm, d2=40cm, dm=120 cm

Piston wave-maker (active wave absorption)

13 wave gauges (G1 to G13)

passive wave absorption

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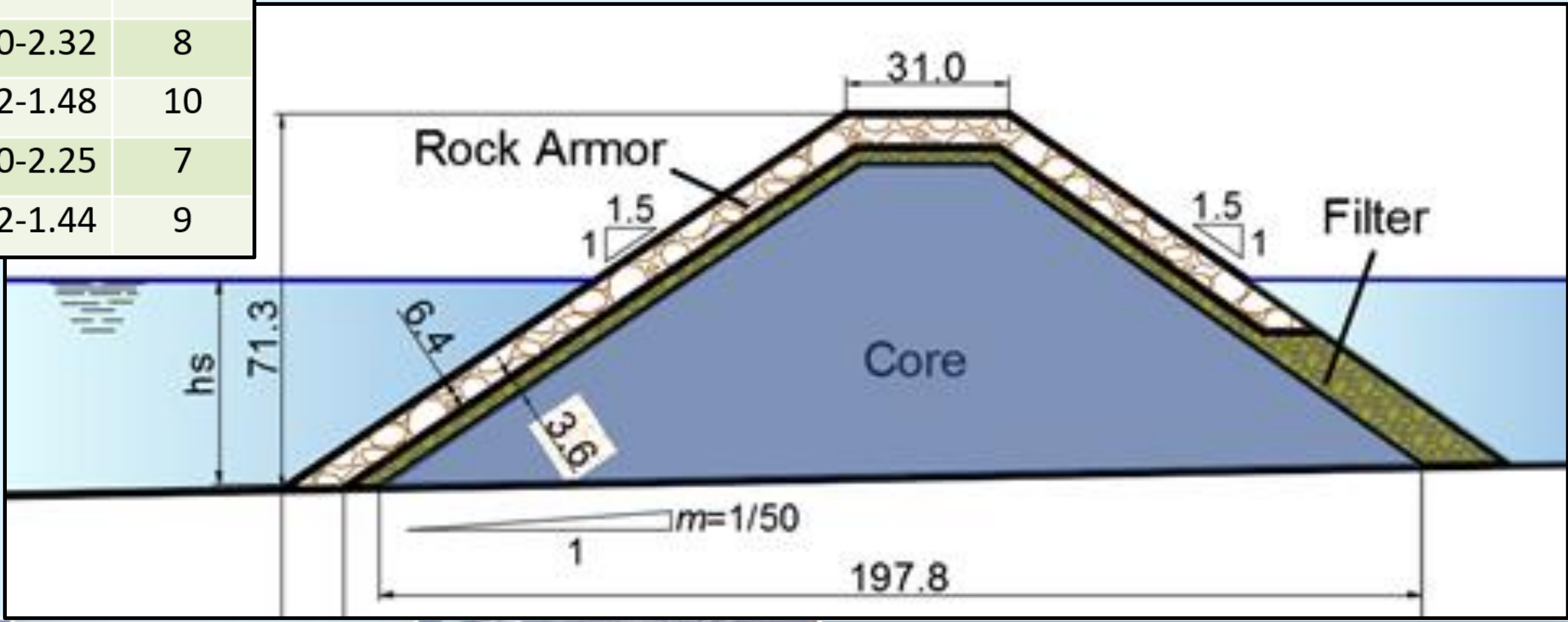
Tests with and without breakwater model (2L rock armor)

(D_{n50}(cm)=3.18, ρ_r(g/cm^3)=2.677, W_{50}(g)=86.1)

Series	h_s(cm)	ξ_p	s_p	H_{m0}(cm)	T_p(s)	#tests
1	20	3.0	0.049	8.0-18.0	1.02-1.53	11
2	20	5.0	0.018	8.0-15.0	1.70-2.32	8
3	30	3.0	0.049	8.0-17.0	1.02-1.48	10
4	30	5.0	0.018	8.0-14.0	1.70-2.25	7
5	40	3.0	0.049	8.0-16.0	1.02-1.44	9



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TESTS WITH BREAKWATER MODEL

Separation Incident + Reflected Waves

LASA-V method (Figures and Medina, 2004)

Incident waves at the wave generation zone (G1 to G4)

Armor damage measurement

Virtual Net (Gómez-Martín and Medina, 2014)

Visual Counting (Vidal et al., 2006)

Numerical model: SwanOne software

SWAN- CWD method

Incident waves (H_{m0},T_p) at wave generation zone

Estimations $H_{2\%}$, $H_{1/10}$ and H_{m0} at G5 to G12

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WAVE ANALYSIS

Tests without breakwater model:

measured waves = incident waves

Tests with breakwater model:

incident + reflected waves at wave-maker

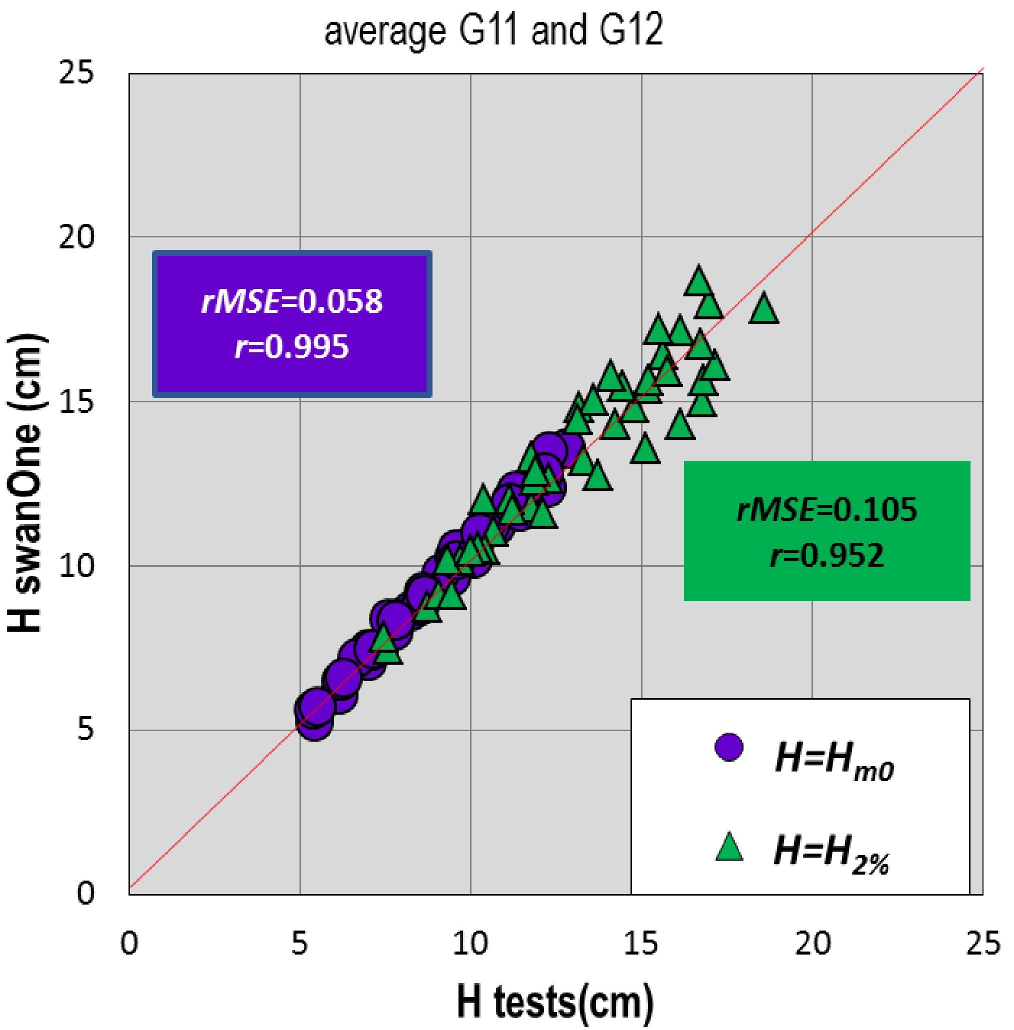
Numerical simulations with SwanOne:

estimated waves = incident waves

$$rMSE = \frac{MSE}{Var} = \frac{\frac{1}{N_o}\sum_{n=1}^{N_o}(e_n - o_n)^2}{\frac{1}{N_o}\sum_{n=1}^{N_o}(o_n - \overline{o})^2}$$

Best agreement: H_{m0} (rMSE=5.8%)

SwanOne explained 94.2% of the variance of measured H_{m0} without structure



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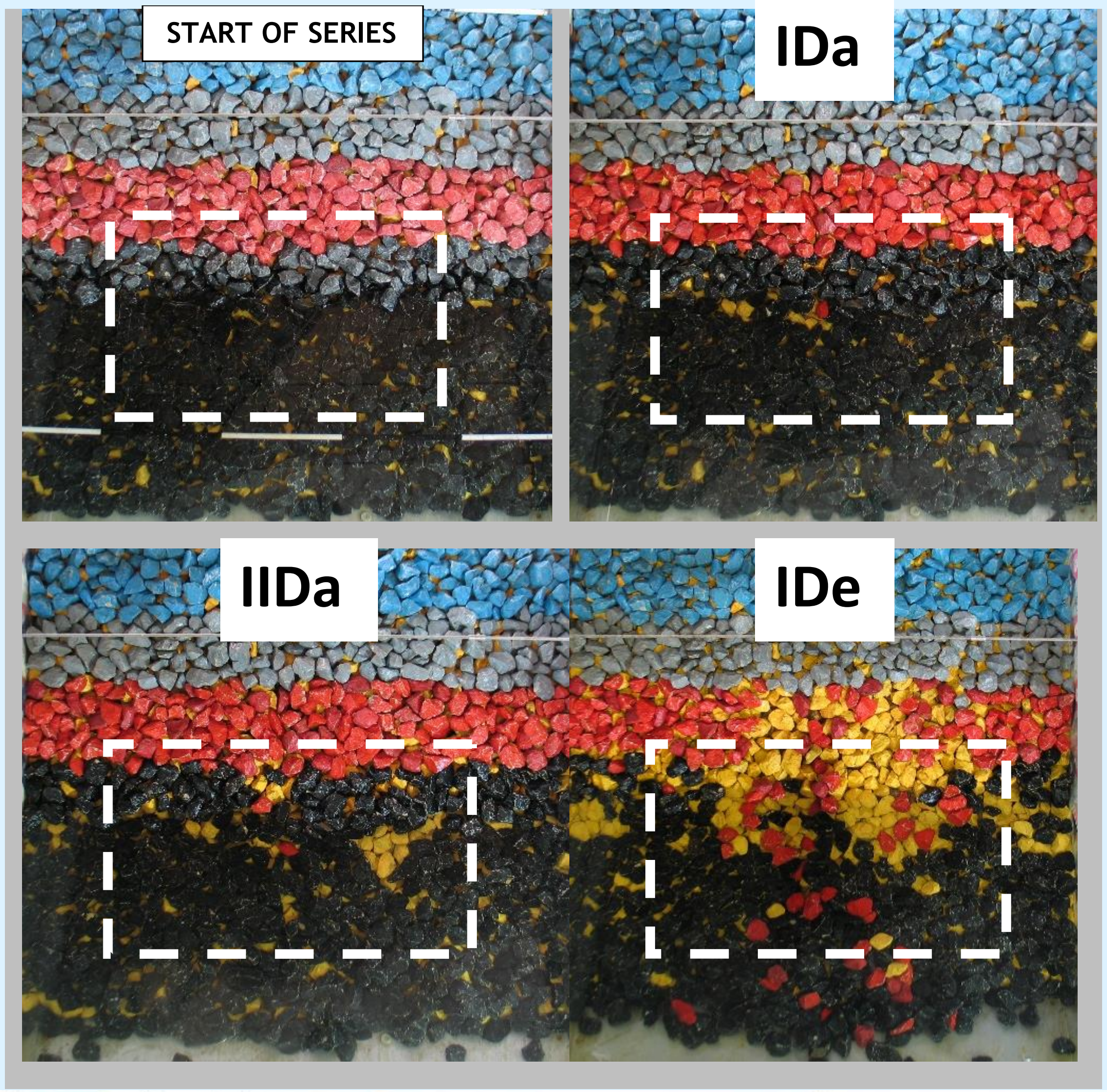
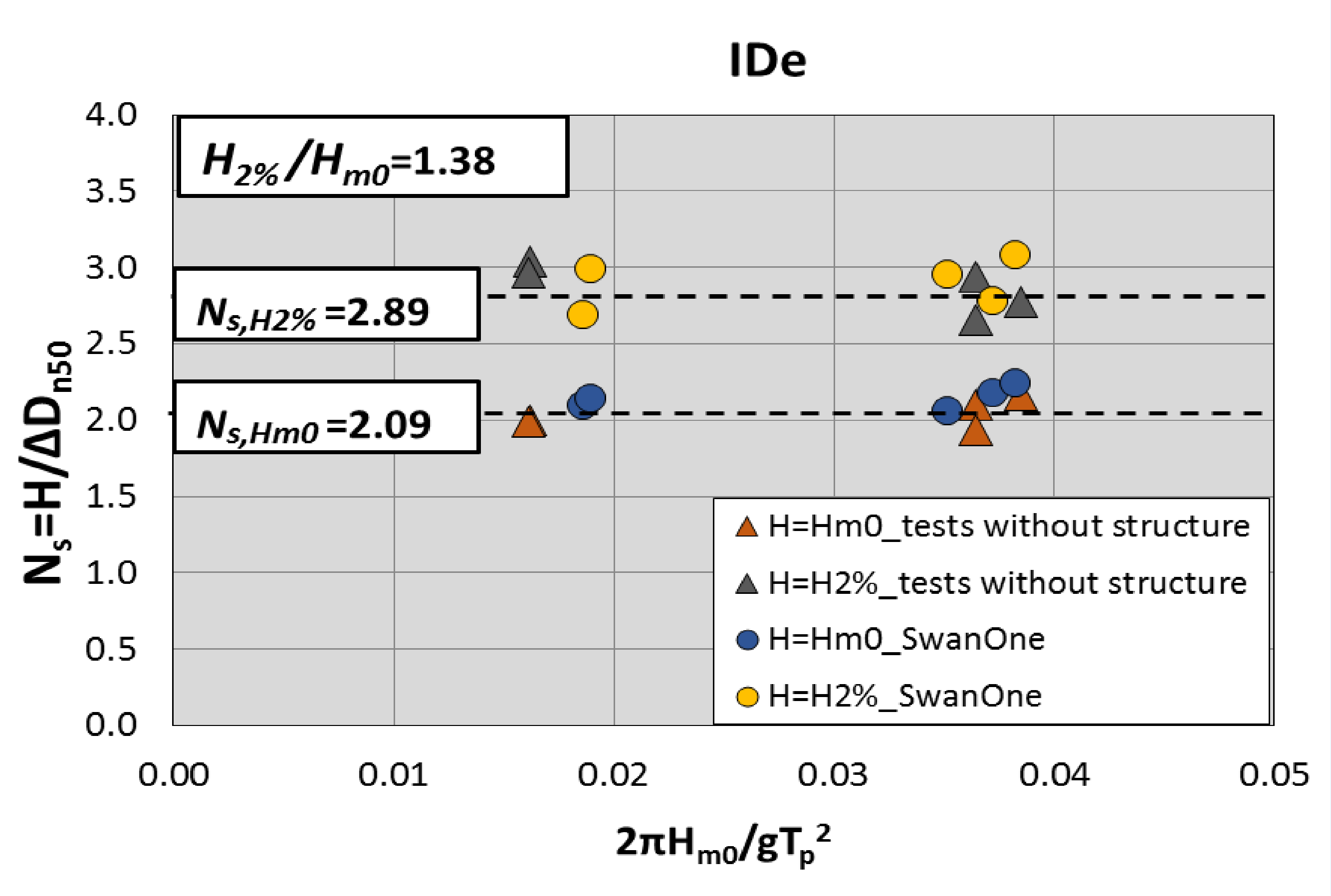


ARMOR DAMAGE MEASUREMENTS



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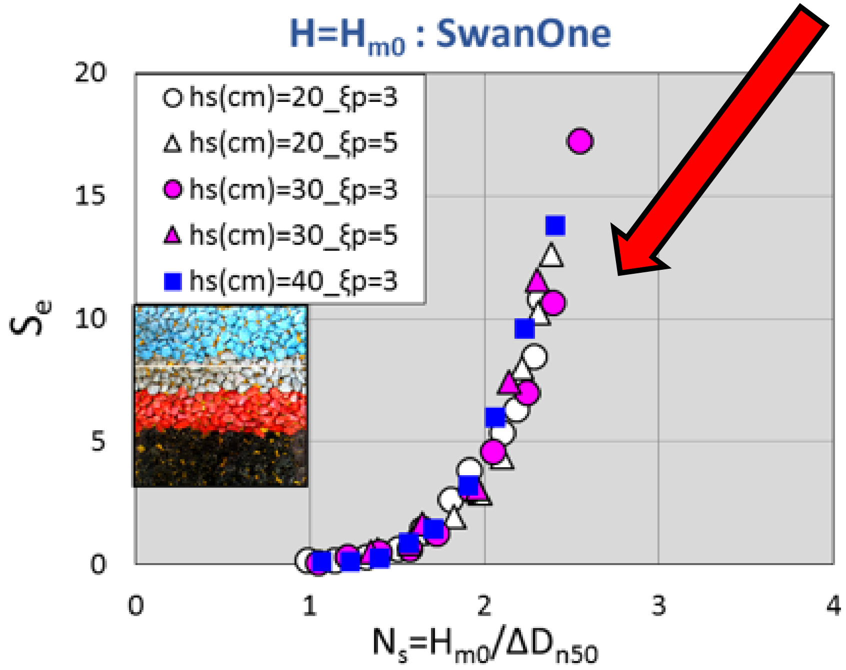
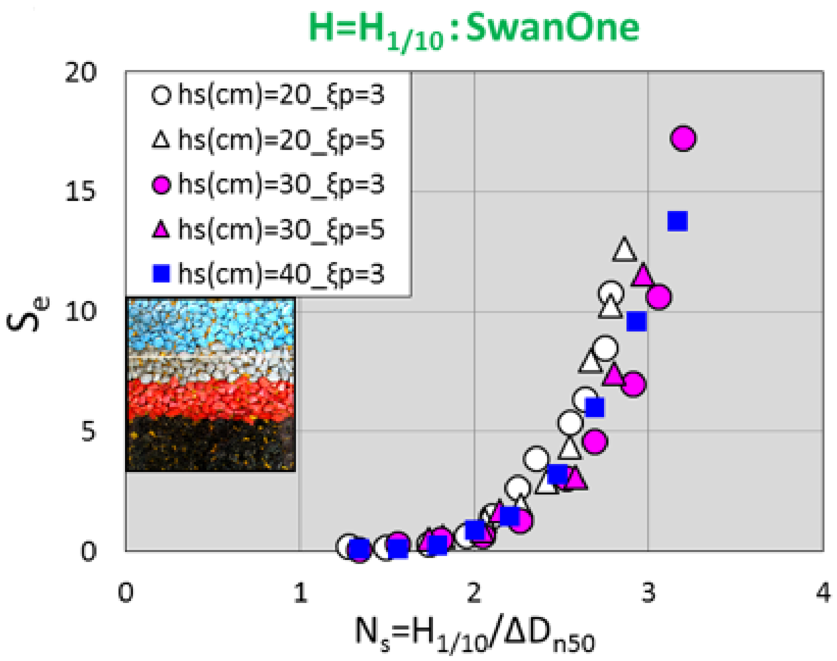
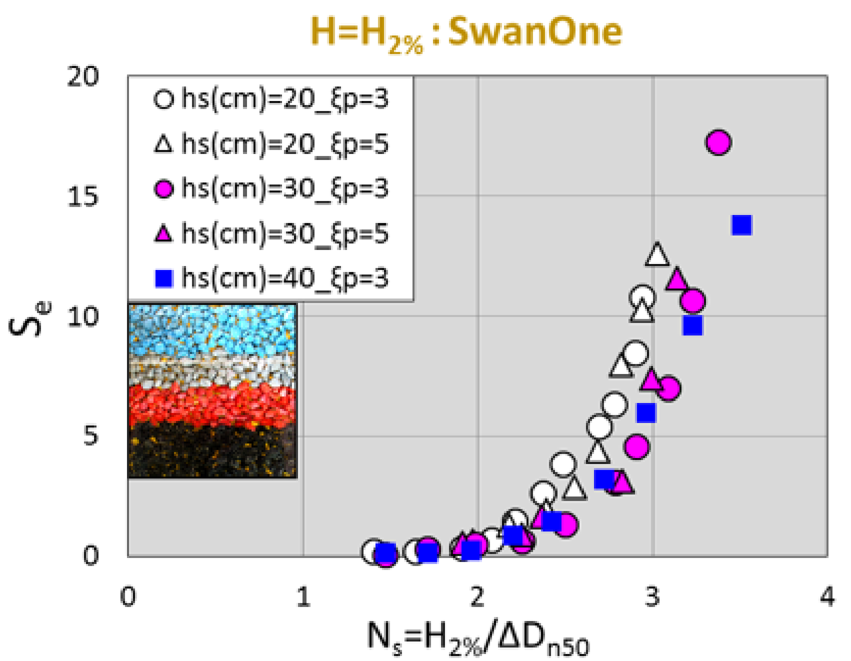
$S_e = S_v = S$

H_{m0} is the best descriptor of armor damage







$$S = k_1 \left(\frac{H}{\Delta D_{n50}}\right)^{k_2} \cancel{(s_m)}^{k_3} \cancel{(h_s)}^{k_4}$$

$H = H_{m0}$

$$S = k_1 \left(\frac{H}{\Delta D_{n50}}\right)^{k_2}$$

$s_m = H_{m0}/L_m$ and h_s discarded (5% significance level)

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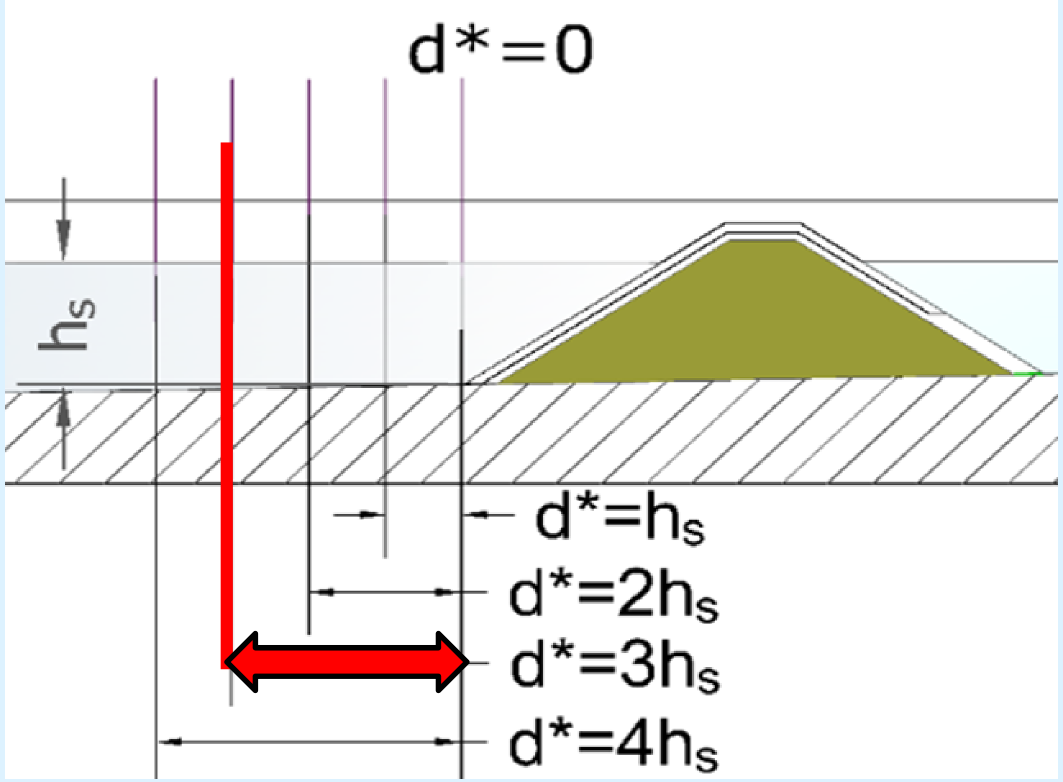
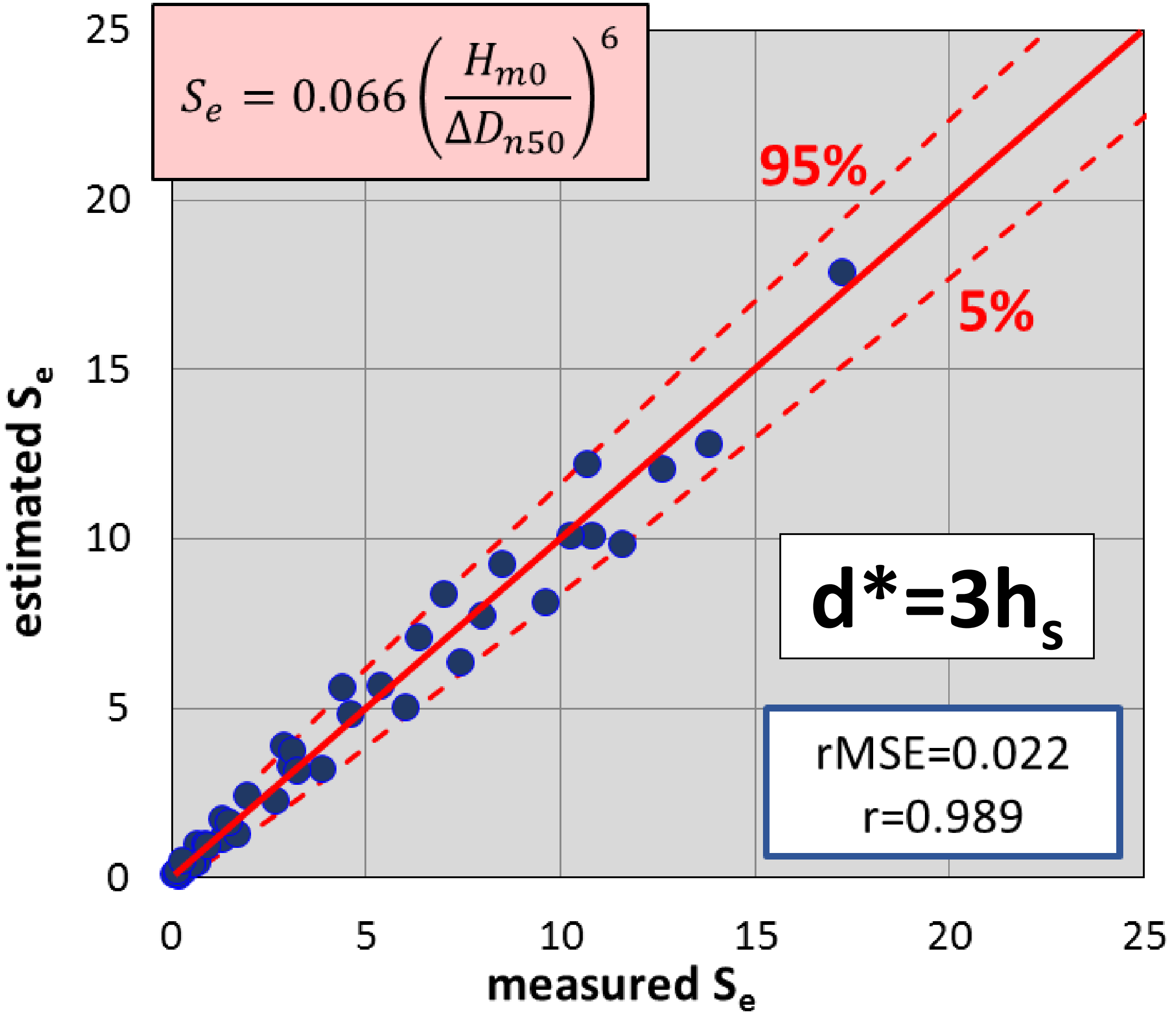
H_{m0} ($d^*=3h_s$) is the best explanatory variable





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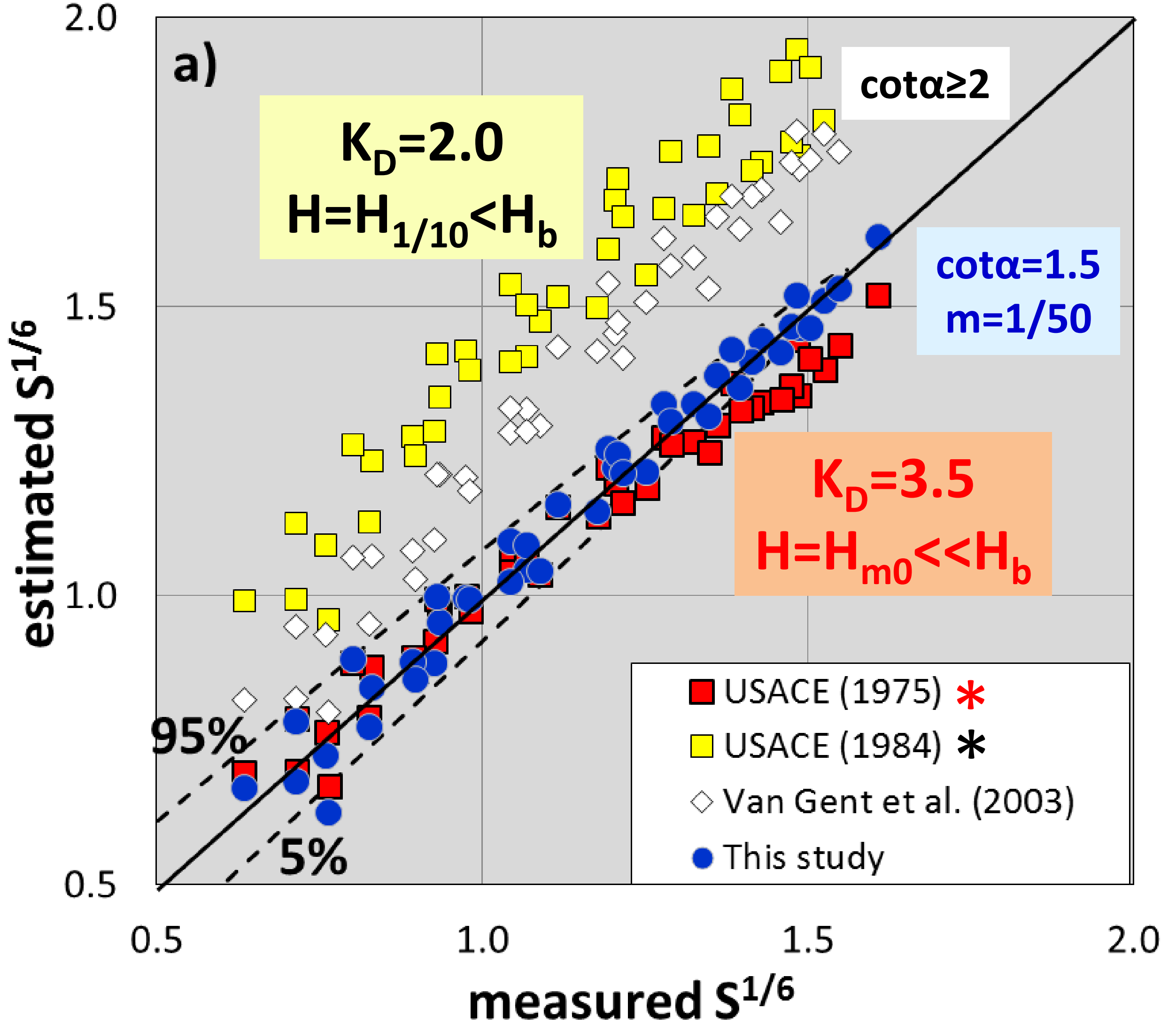

m=1/50 and cotα=H/V=1.5
H_{m0} ($d^*=3h_s$)

$$S = 0.066\left(\frac{H_{m0}}{\Delta D_{n50}}\right)^6$$

$$N_s(50\%) = \frac{H_{m0}}{\Delta D_{n50}} = 1.57 \cdot S^{1/6}$$

$$N_s = \frac{H}{\Delta D_{n50}} = 1.62 \cdot S^{1/5}$$

USACE* (1975)
$H=H_b>>H_{m0}$
SF≈1.4

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HYDRAULIC STABILITY OR ARMOR LAYERS

Most **physical tests** in **non-breaking wave conditions**
Design formulas based on non-breaking wave conditions
Methods to separate **incident and reflected (I+R) waves**

Most **structures** built in **depth-limited breaking wave conditions**
Nonlinear effects and **no method to separate I+R waves** (h_s, 1/m, s_m)

$S = k\,N_s^5$?

Breaker Index method (Goda, 1974 to 2012)
CWD Method (Battjes and Groenendijk, 2000) → **SWAN – SwanOne**

I+R waves (wave generation) → **SWAN** → **H_{m0}, $H_{2\%}$ (foreshore)**

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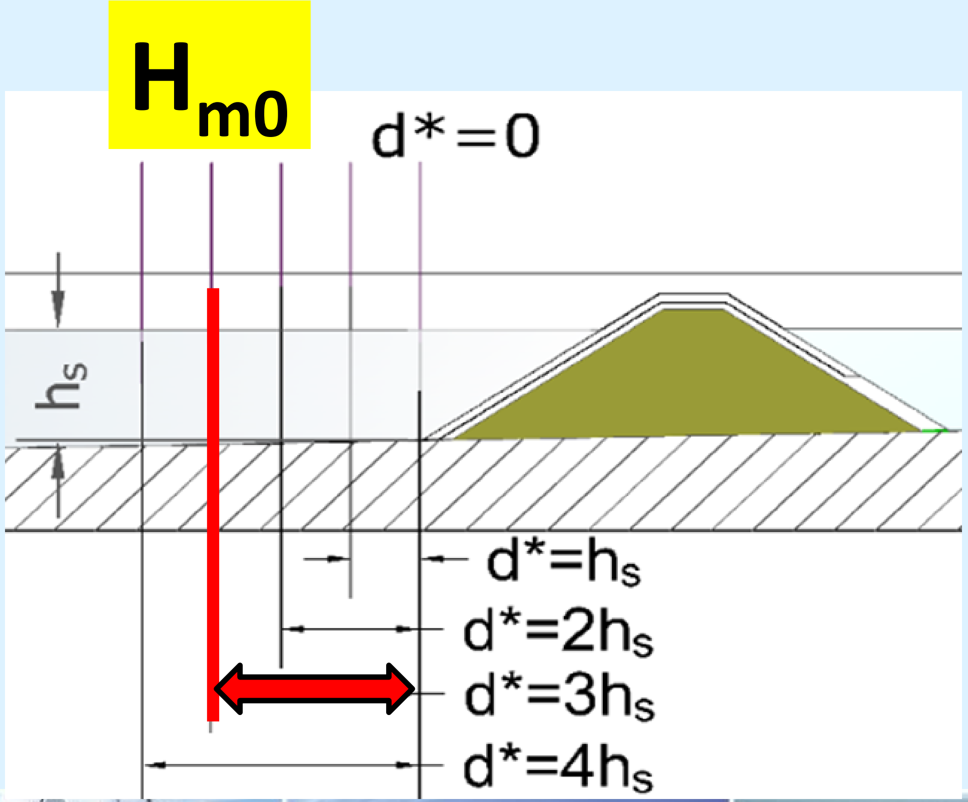
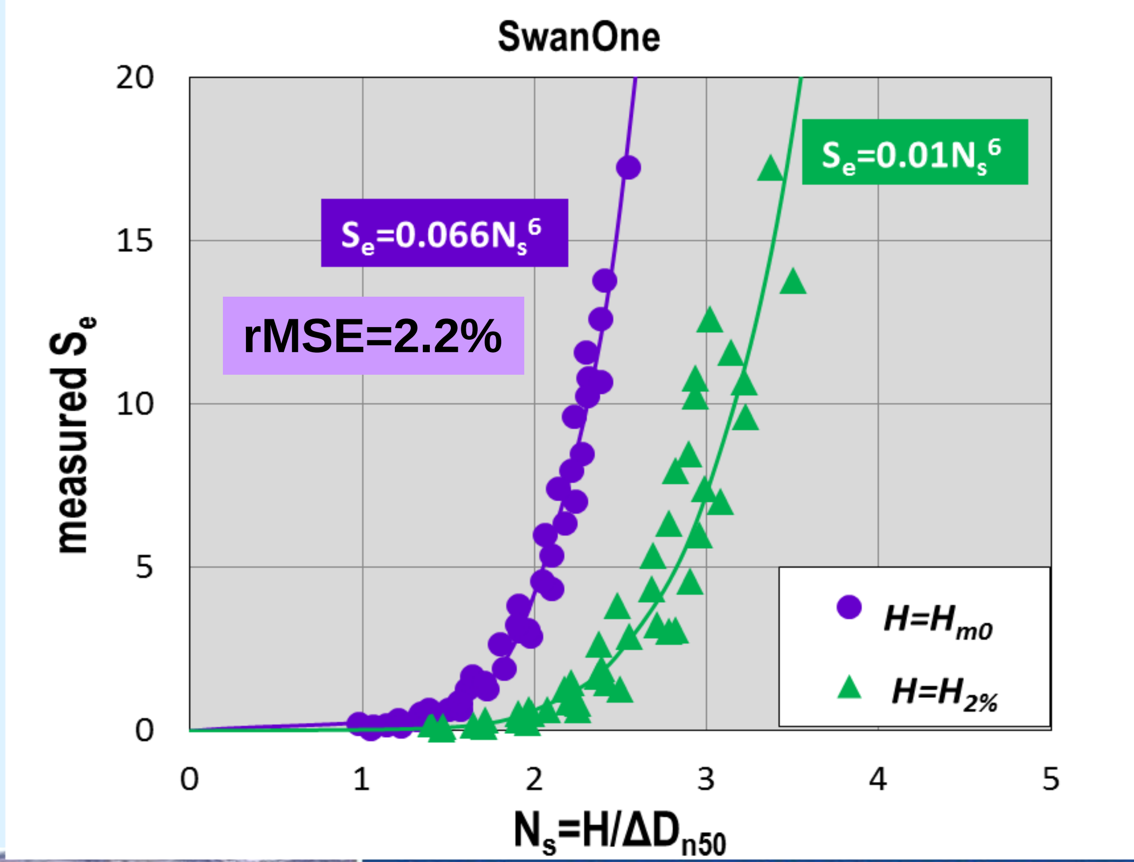
$$S = k_1 \left(\frac{H}{\Delta D_{n50}}\right)^{k_2} \cancel{(s_m)}^{k_3} \cancel{(h_s)}^{k_4}$$

m=1/50

CWD (SWAN)

$$S = 0.066 \left(\frac{H_{m0}}{\Delta D_{n50}}\right)^6$$





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