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SECOND ORDER DRIFT FORCES ON "OFFSHORE" WAVE ENERGY CONVERTERS

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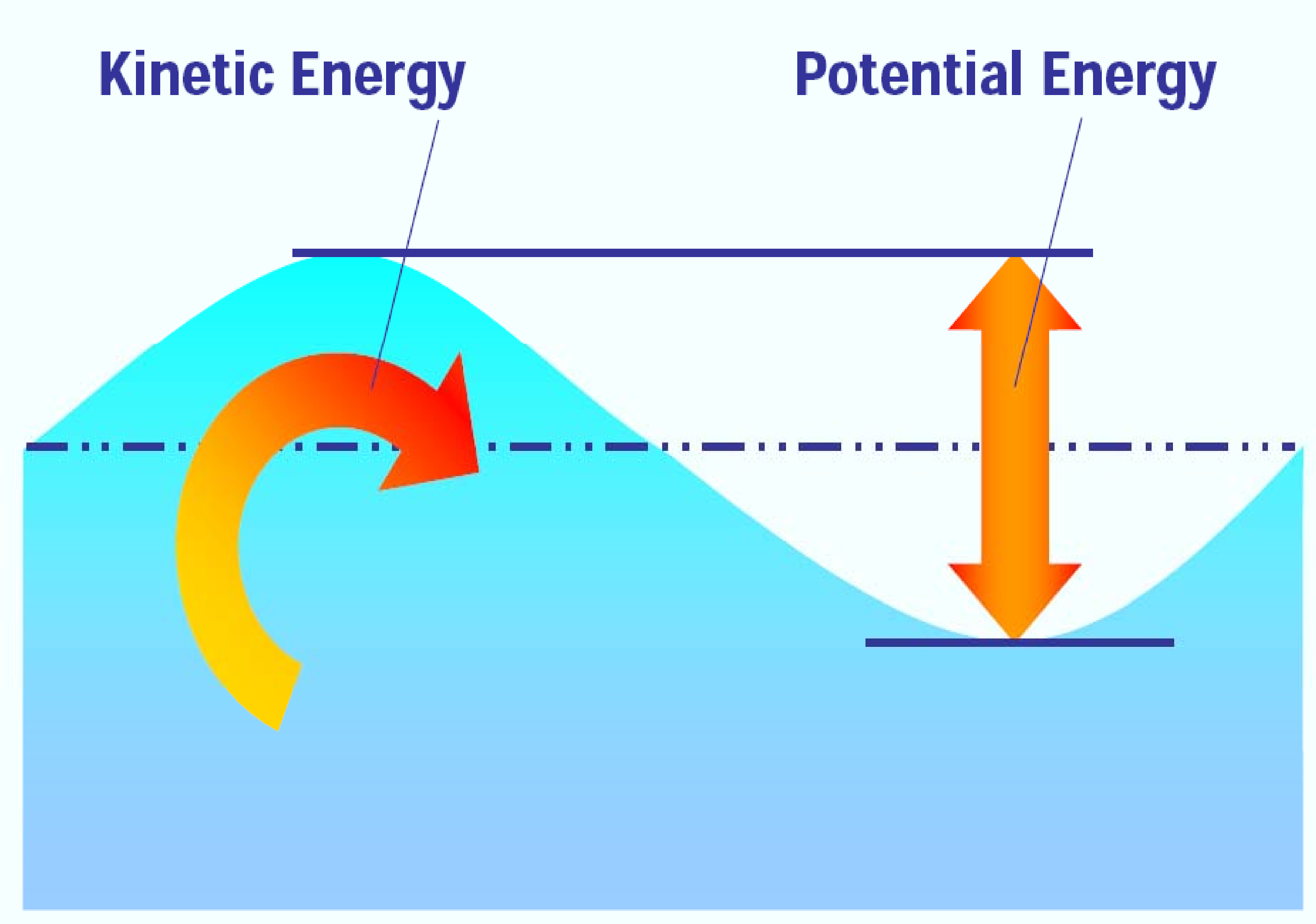
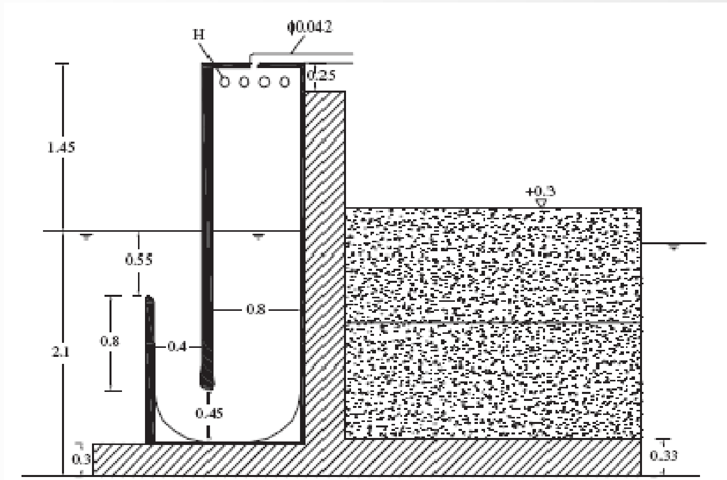
Layout

- Introduction on Wave Energy Converters
  - Potential
  - Classification
  - Examples
  - Laboratory tests
- Motivations for this study (2nd order…)
- Peculiarities of the application
- Conclusions

Wave Energy



REWEC3



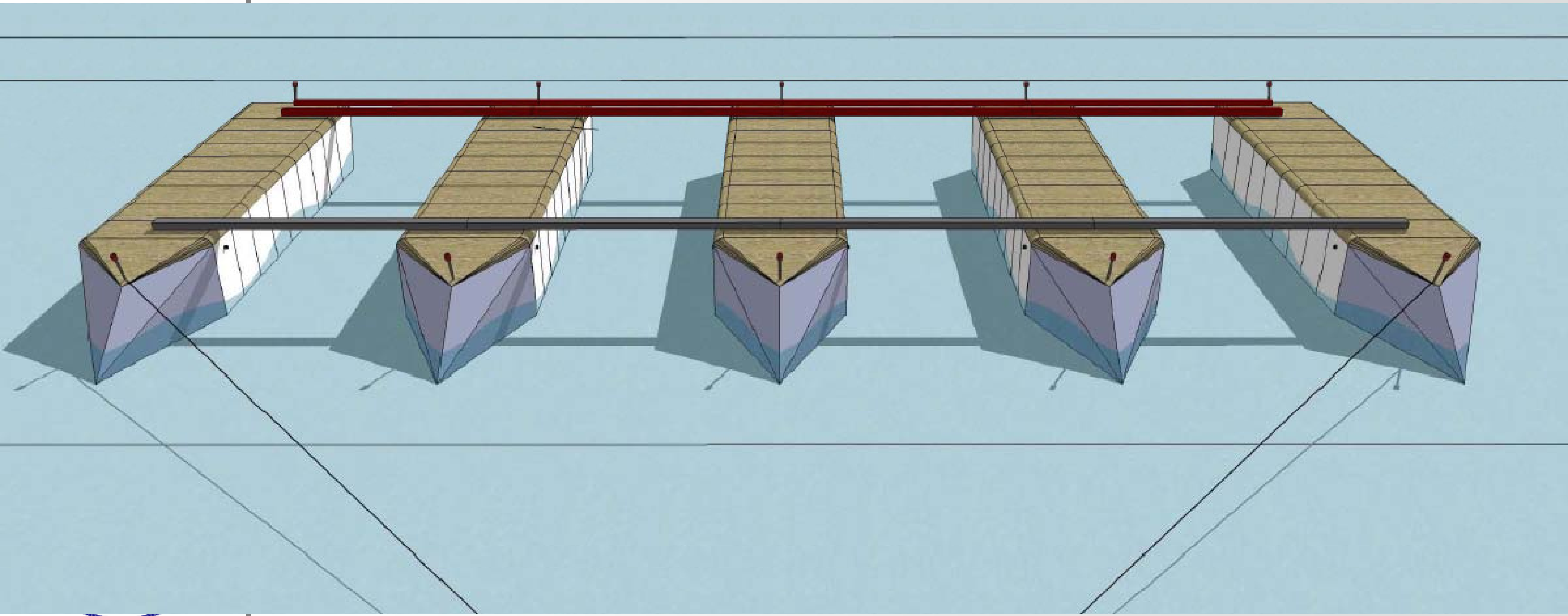
Boccotti et al. Ocean Engineering 34 822 (2007) 820–841

7 GWh/y/Km of breakwater (Ponza)
Cost: 7% more than traditional vertical brkw

HYDRAULIC EFFICIENCY 60-100%
Comune di Leni (Messina), isola di Salina (Eolie)
Several sound possibilities of installation
(e.g. Porto Gioia Tauro)

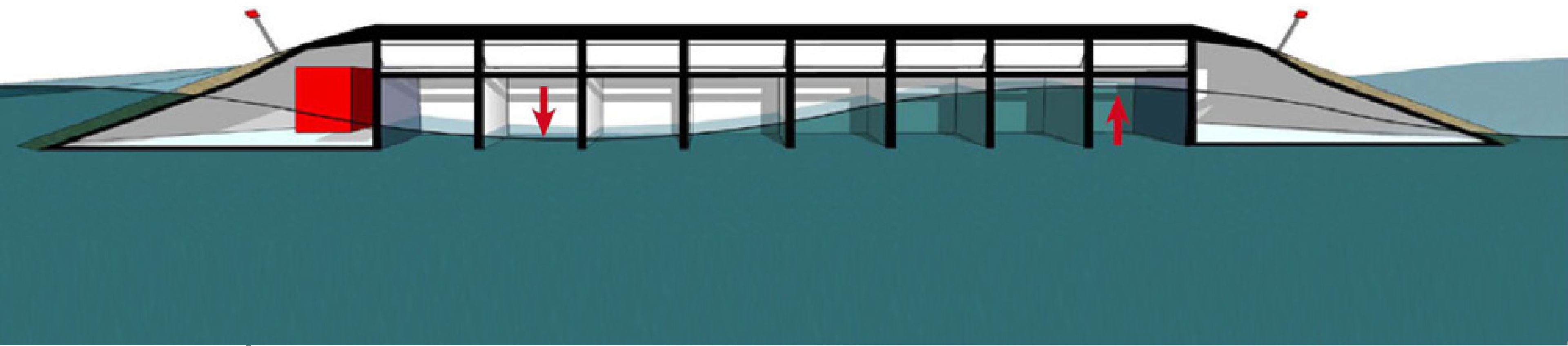
Sea Breath
Artist’s impression of placement in an array structure

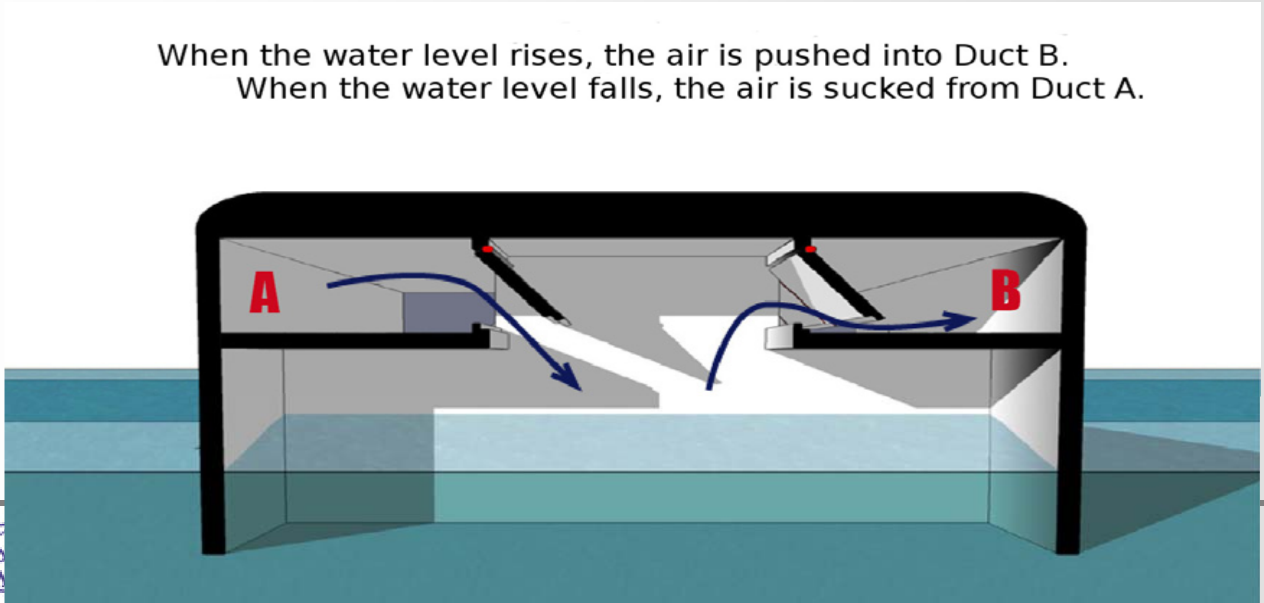
Multi Absorbing Oscillating Water Column (MAWEC)



Sea Breath

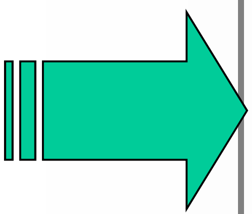
The wave is divided into different levels in the sectors



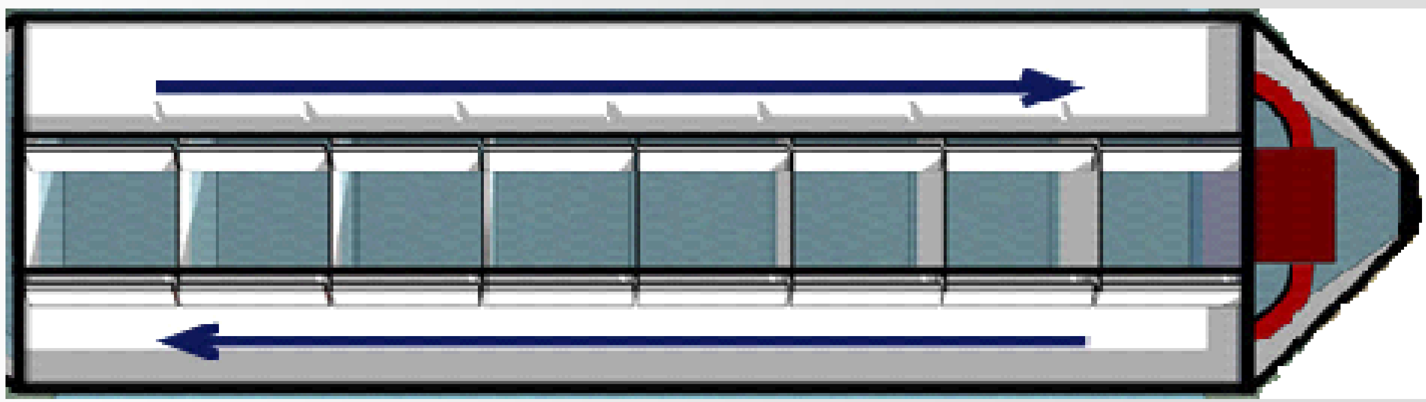


Concept

The circle of air feeds a turbine

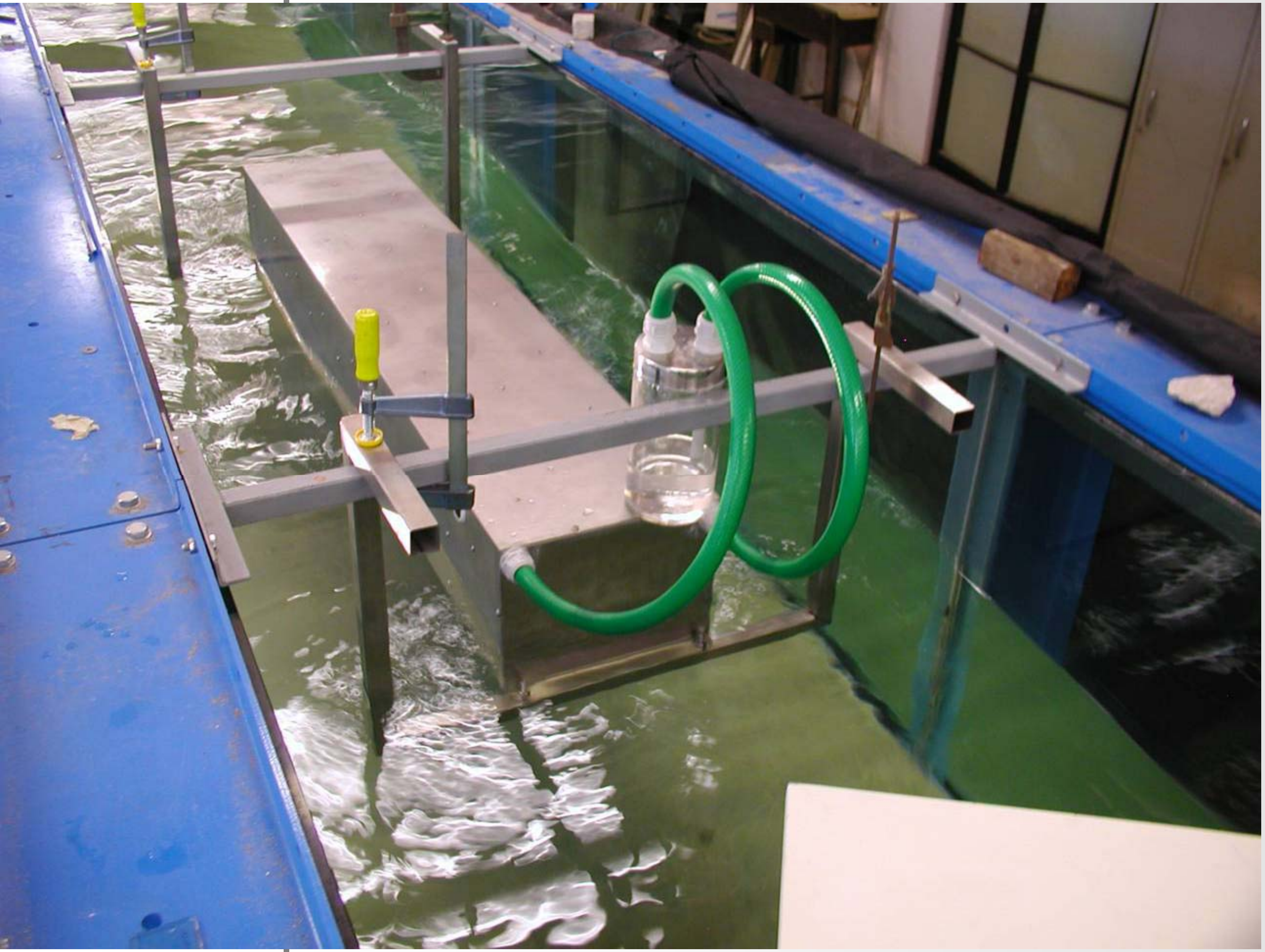


Wave direction



Inventor: Luigi Rubino
Patent n.: PCT/IB2009/051646
Priority:PR2008A000027
Luigirubino@hotmail.com

Physical model tests

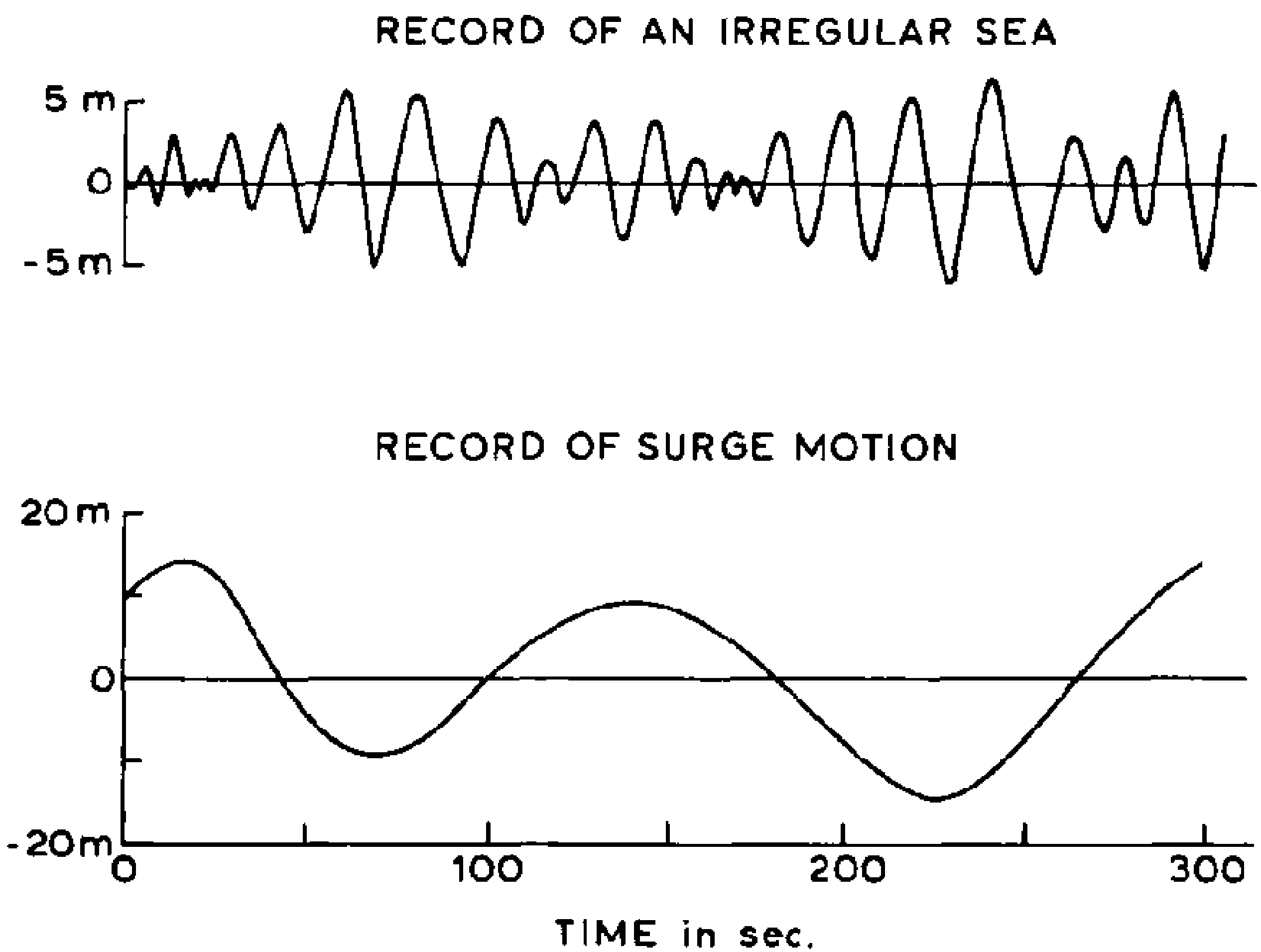


New tests planned, aiming at R&D

Padova University, Italy

OE Buoy

Record of mooring force



Objectives

Present a procedure for evaluating 2nd order drift forces on floating bodies, often the most important loading component for mooring design, in case of high waves propagating in “relatively” shallow water depths.

Irrotational flow around floating body

$$\nabla^2\Phi=0$$

$$\Phi=(\Phi_I+\Phi_S)+V\,\Phi_H$$

Channel+ Effect of fixed FB + Effect of movements

$$\Phi=\varepsilon\,\Phi^{(1)}+\varepsilon^2\,\Phi^{(2)}+O(\varepsilon^3)$$

$$\eta=\eta^{(0)}+\varepsilon\,\eta^{(1)}+\varepsilon^2\,\Phi^{(2)}+O(\varepsilon^3)$$

$$\overline{X}=\overline{X}^{(0)}+\varepsilon\;\overline{X}^{(1)}+\varepsilon^2\,\overline{X}^{(1)}+O(\varepsilon^3)$$

$$\Phi^{(1)}=\Phi_I^{(1)}+\Phi_S^{(1)}+\sum V_i^{(1)}\Phi_i^{(1)}$$

$$\Phi^{(2)}=\Phi_W^{(2)}+\Phi_S^{(2)}+\sum V_i^{(2)}\Phi_i^{(2)}$$

Regular wave - phasor variables

$$A(x,t)=a(x)\cos(\omega_1 t+\varepsilon_1(x)) = +\mathrm{Re}[\phi(x_1)e(i\omega_1 t)]$$

Peculiarity of the method is how to compute the product of two phasor variables

$$A(x,t)=a(x)\cos(\omega_1 t+\varepsilon_1(x)) = +\,\mathrm{Re}[\phi(x_1)e(i\omega_1 t)]$$
$$B(x,t)=b(x)\cos(\omega_2 t+\varepsilon_2(x)) = +\,\mathrm{Re}[\psi(x_1)e(i\omega_2 t)]$$

$$A^*B = \mathrm{Re}[0.5\phi\psi\, e(i\omega_S t)+0.5\phi\psi^C\, e(i\omega_D t)])$$
where $\omega_S=\omega_1+\omega_2$ *and* $\omega_D=\omega_1-\omega_2$

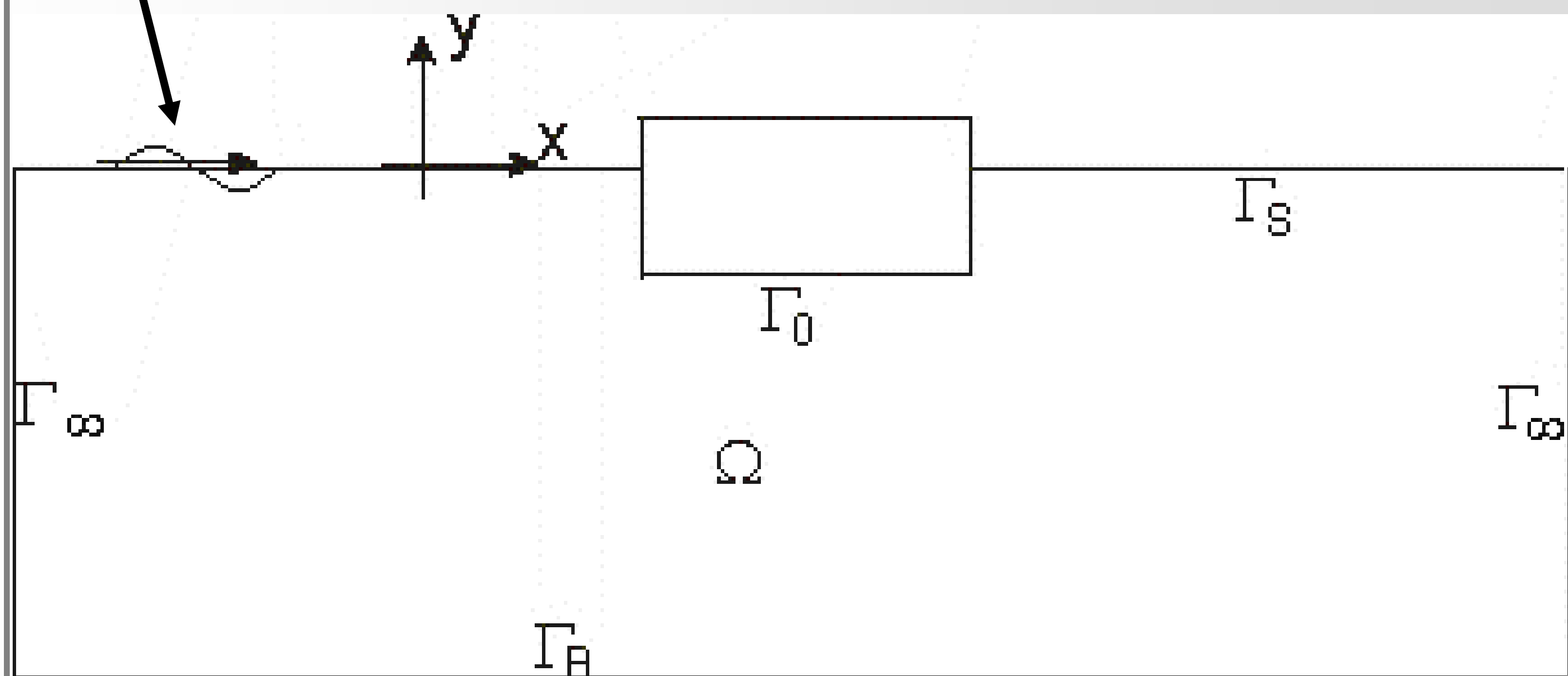
$$\rightarrow \qquad \Phi_w^{(2)} = \Phi_{wHF}^{(2)} + \Phi_{wLF}^{(2)}$$

And we can differentiate in time the unknown potential!

Incident 1st order potential

$$\Phi^{(1)}{}_{I}$$

$$\Phi_I = \mathrm{Re}\left[-\frac{iHg}{2\omega} \frac{\cosh(k(y+d))}{\cosh kd} e^{i(\omega t - kx)} \right]$$

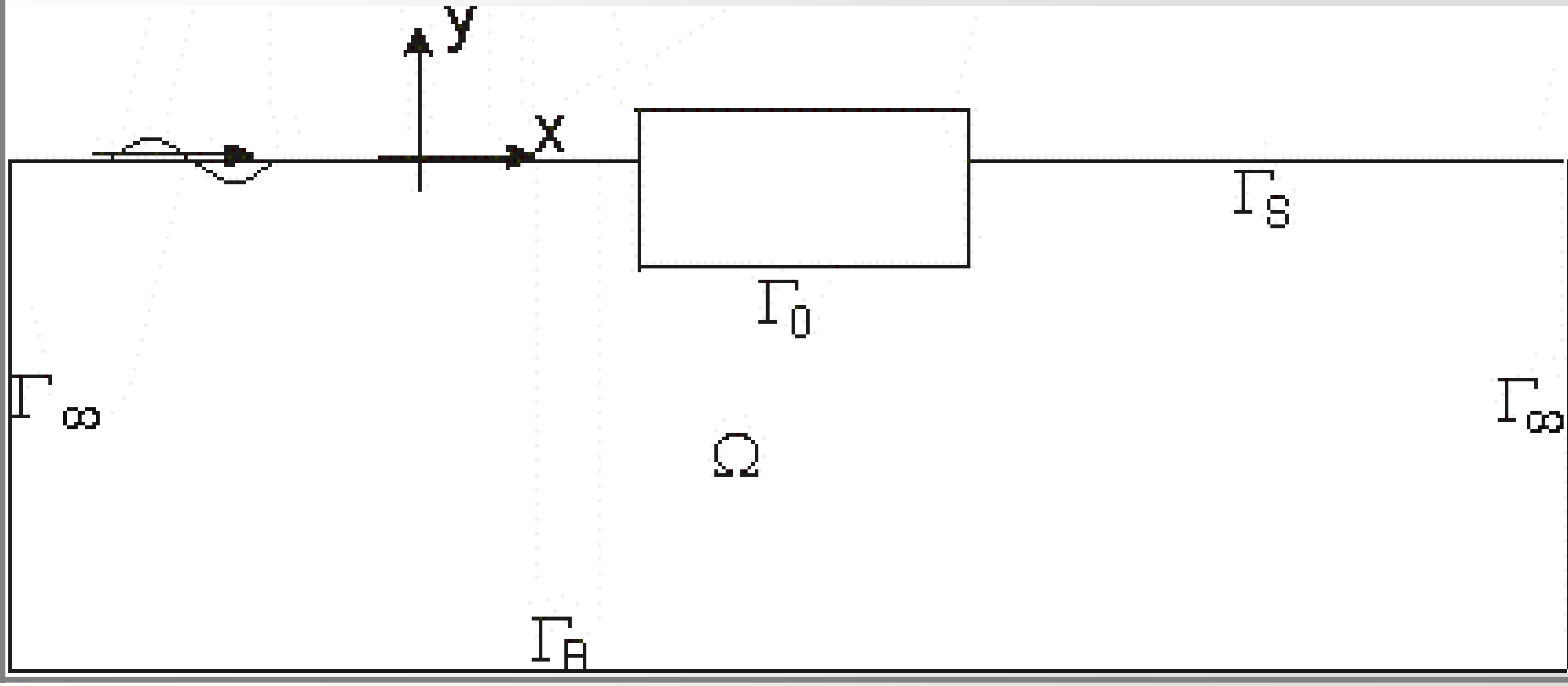


Domain equation

$$\nabla^2 \Phi^{(1)} = 0$$

$$\nabla^2 \Phi^{(2)} = 0$$

in Ω



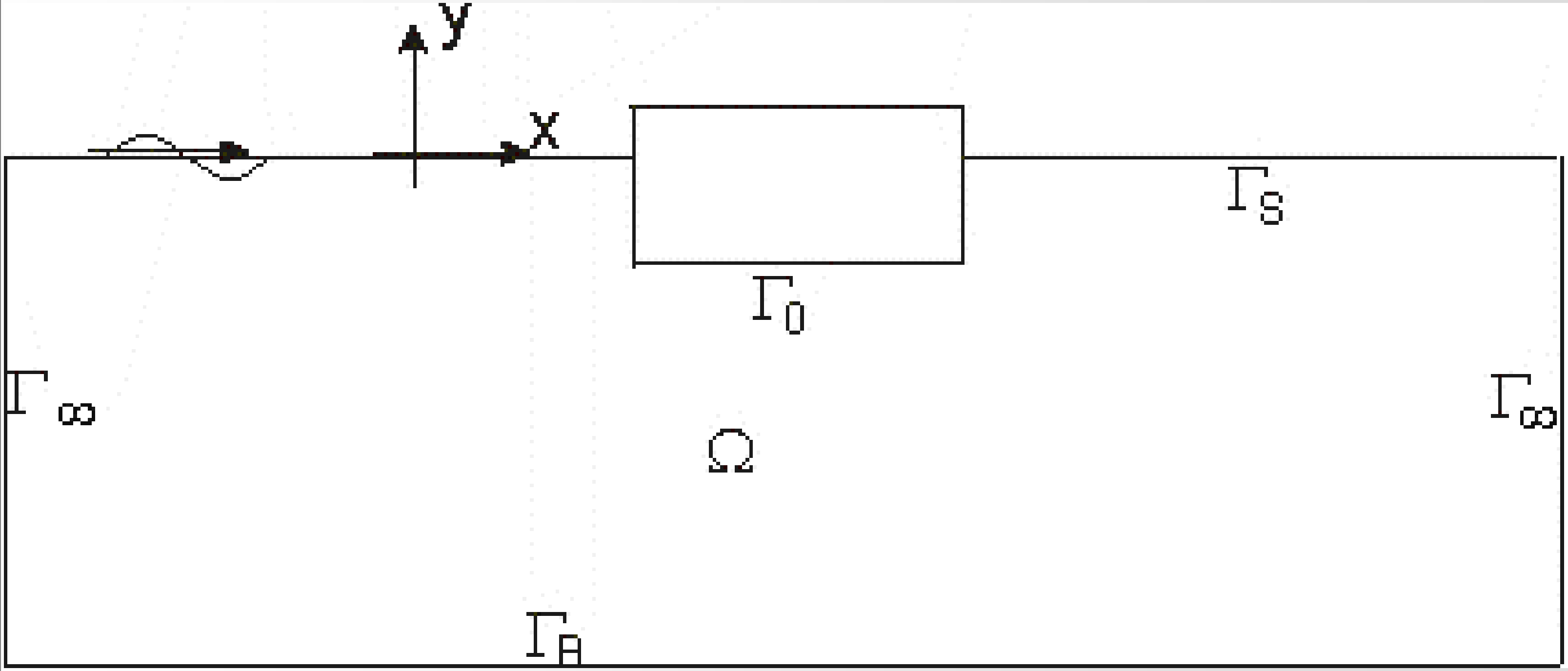
2.1 Surface boundary conditon

$-n\,\Gamma = \omega^2/g\ \phi_S$ in Γ_S ($\phi^{(1)}{}_s$, $\phi^{(2)}{}_s$ and radiated, e.g

$$\Phi^{(2)}_{sLF,z} = -1/g[-\omega_D{}^2\Phi^{(2)}_{sLF}]$$)

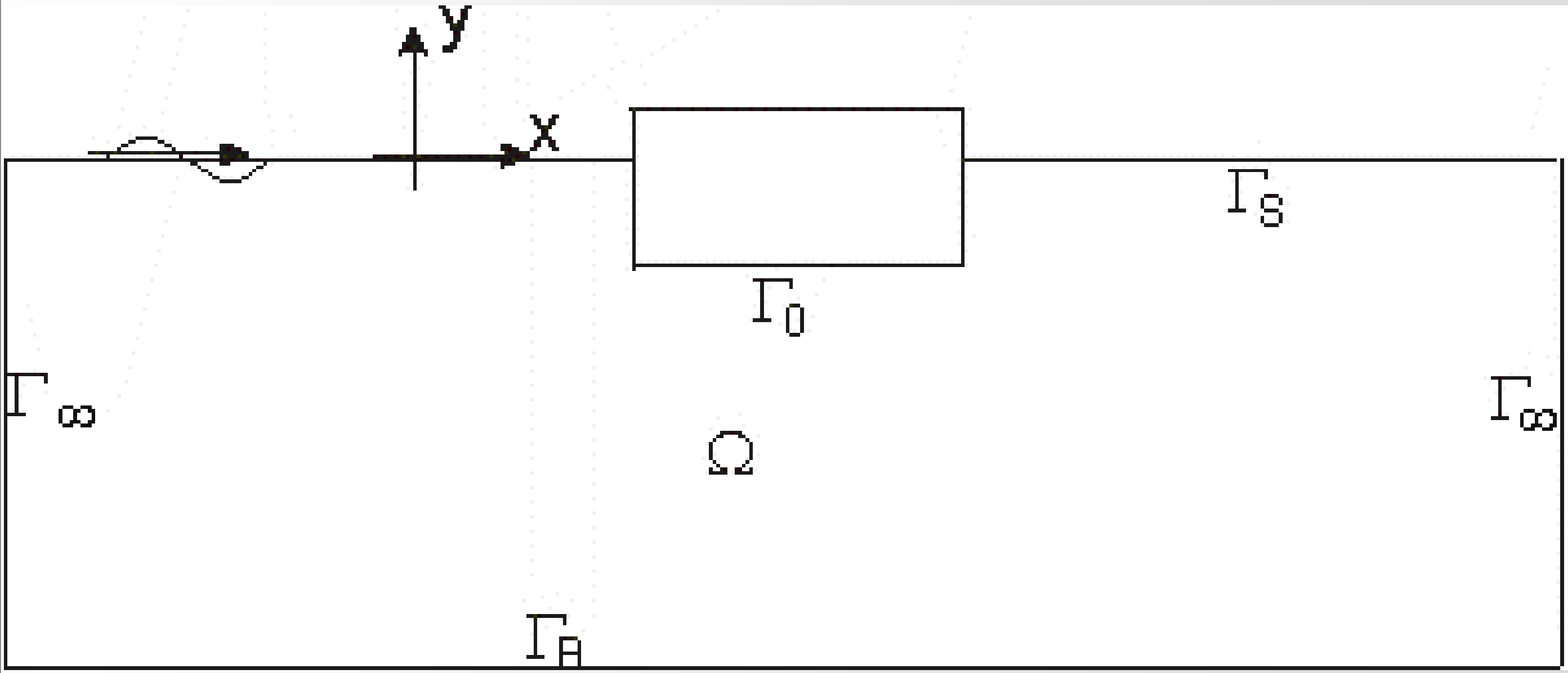
$$-\Gamma n = \Phi^{(2)}_{w,z} = -1/g[-\omega^2\Phi^{(2)}_{w} +$$

$$2\nabla\Phi^{(1)}\nabla\Phi^{(1)} + i\omega\Phi^{(1)}\left(\Phi^{(1)}_{,zz} - \Phi^{(1)}_{,z}\omega^2/g\right)]$$



2.1 Radiation condition

$-n\,\Gamma = i\,k\,\phi$ in Γ_∞ (ϕ_I already satisfy this)

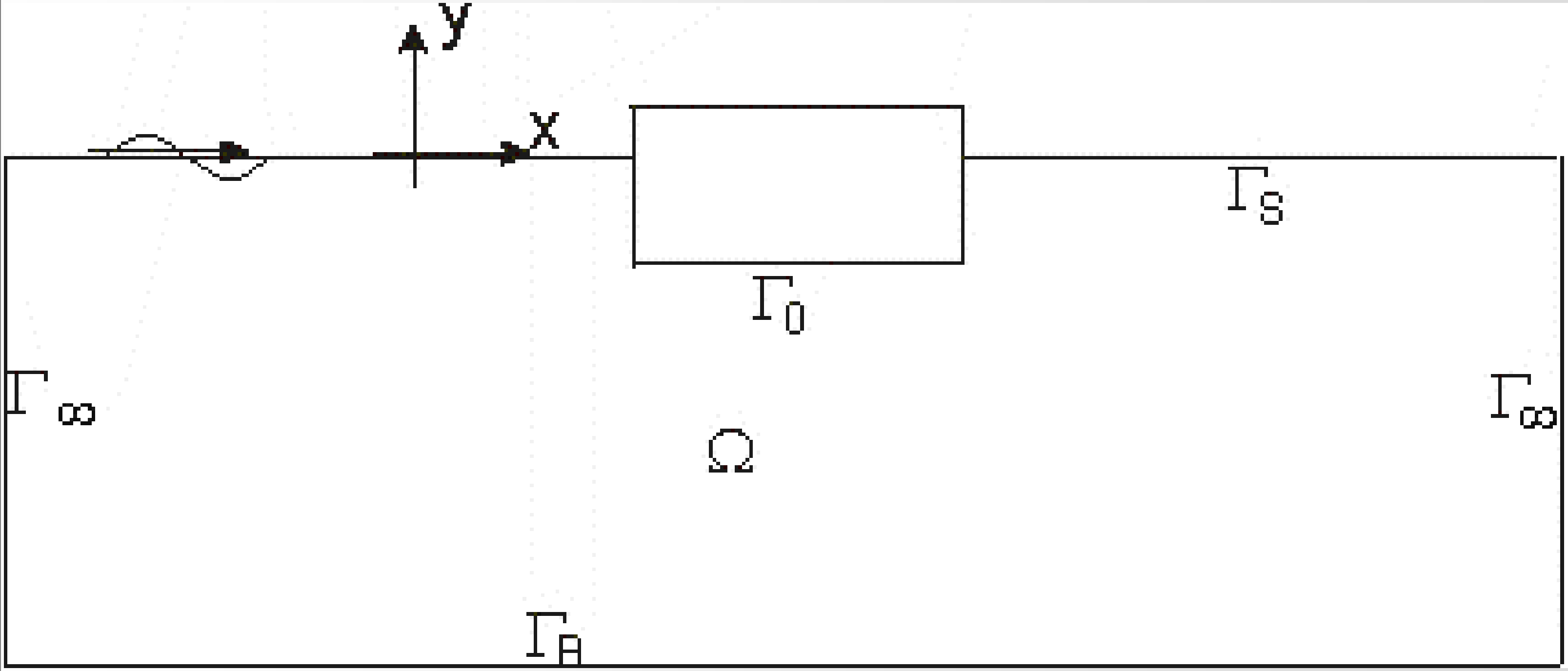


Condition at body

$-n\,\Gamma = -\,n\,\nabla\phi_I$ in Γ_B and Γ_0

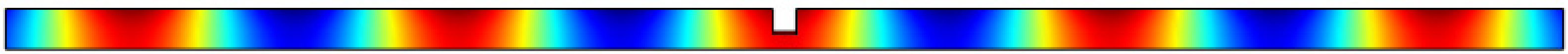
so that: $\nabla(\phi_I+\phi_S)n=0$ for 1st and second order terms,

except: $$\nabla\Phi_s^{(2)} n = (X^{(1)}\cdot\nabla)\nabla\Phi^{(1)} n + -(V^{(1)} - \nabla\Phi^{(1)})N^{(1)}$$

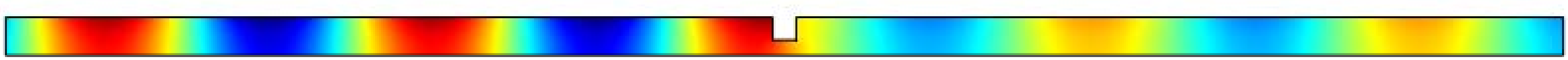


1 wave

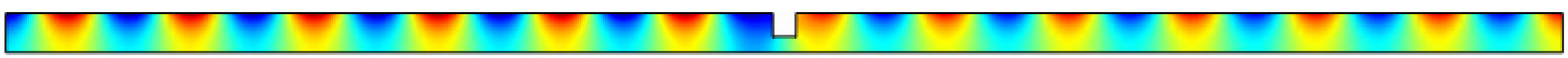
incident



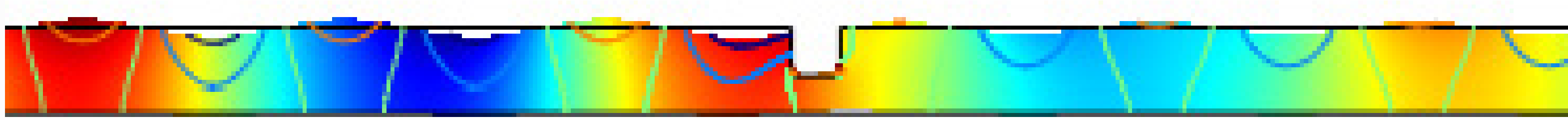
Incident+ scattered



Wave 2nd Hfreq

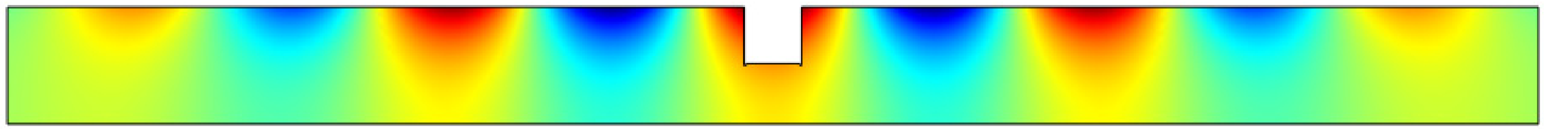


Total potential (fixed body) ZOOMED VIEW:

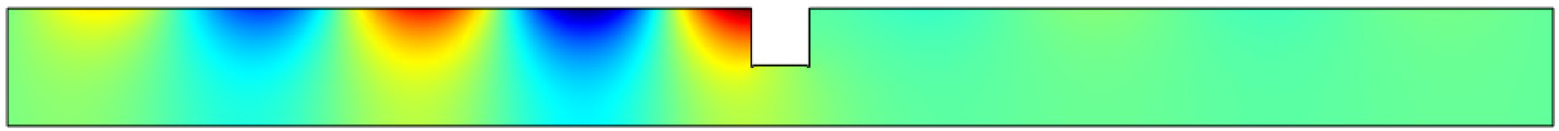


2 waves

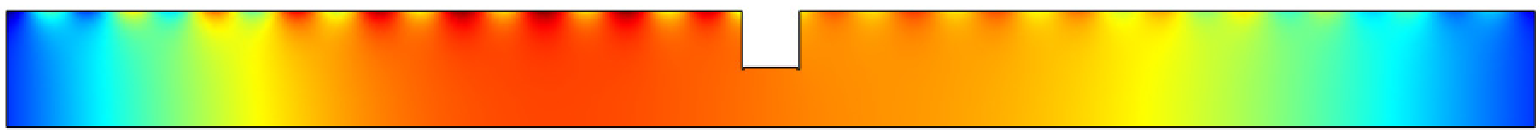
incident



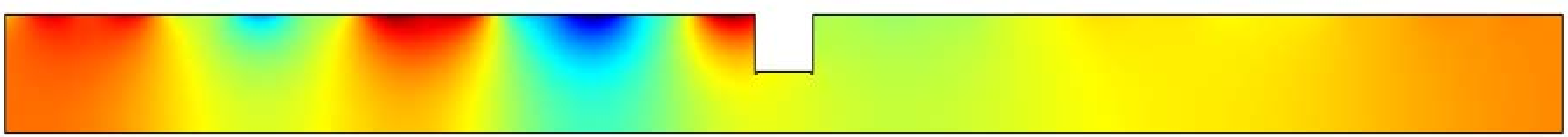
Incident+ scattered

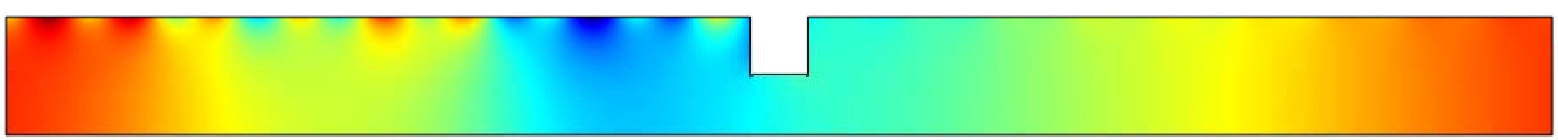


Wave 2nd



Total potential (fixed body): small & high wave hight





1st Order Force

Force on FB = integral of 1st order pressure

Exciting force (=fixed structure) +
force due to radiation (for unit vel) in phase with acceleration (i.e. added mass) or relative to propagating waves (i.e. damping)

$$F^{e}_{v} = \int i\omega\rho(\phi_I + \phi_S) n_y \mathrm{d}\Gamma_0$$

$$f_v = \int i\omega\rho\phi_H n_y \mathrm{d}\Gamma_0 = i\omega\mu - \lambda$$

$$(-\omega^2(M+\mu) + i\omega\lambda + \rho g W)\, \upsilon = F_v^e$$

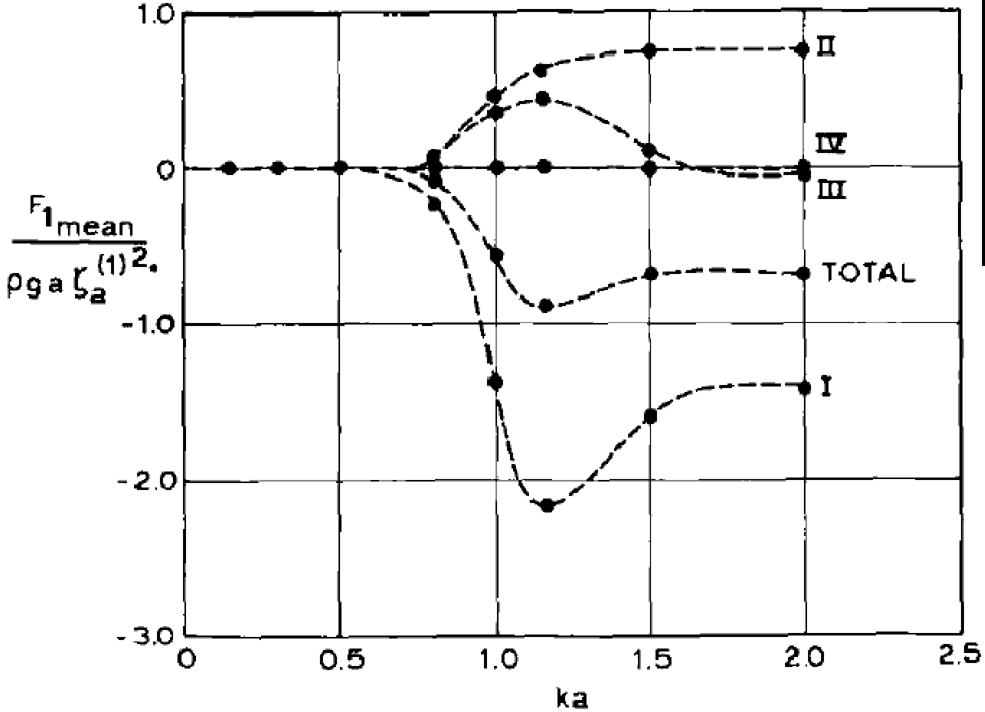
2n Order Drift Force

$$\overline{F}^{(2)} = -\oint_{wl} \frac{1}{2}\rho g \left(\eta_R^{(1)}\right)^2 \overline{n}\, dl +$$

$$\oint_{So} \frac{1}{2}\rho \left|\nabla\Phi^{(1)}\right|^{(2)} + \rho\left(\overline{X}^{(1)}\overline{\nabla}\Phi_t^{(1)}\right)\overline{n}\, dS$$

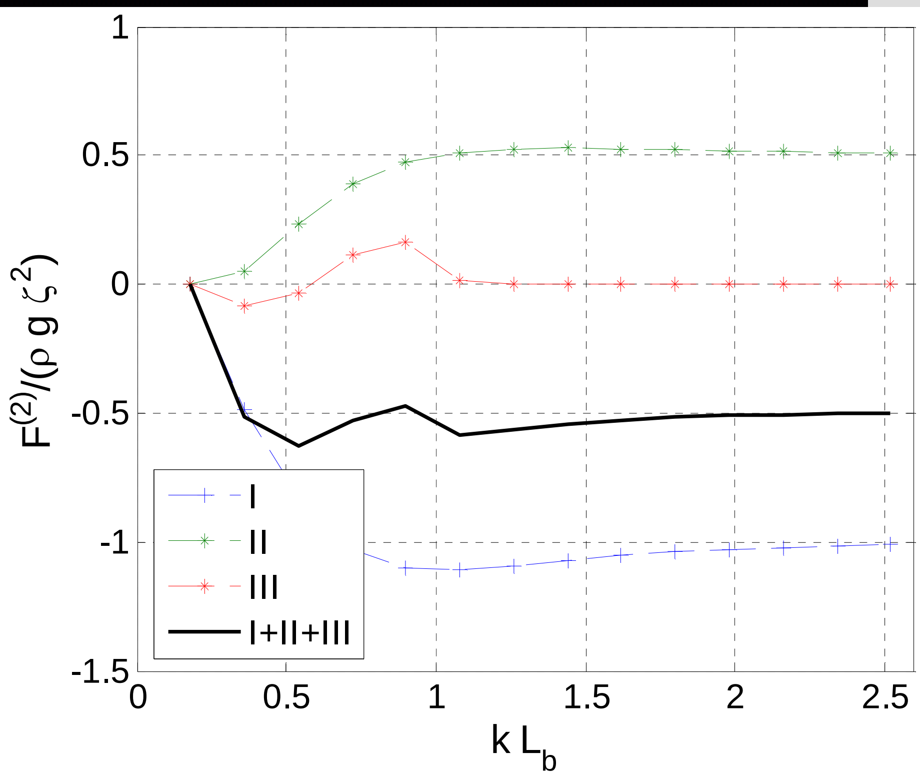
$$+\overline{\alpha}^{(1)} \times \left(M\ddot{\overline{X}}^{(1)}\right) + \oint_{So} \left(\rho\Phi_{w,t}^{(2)} + \rho\Phi_{d,t}^{(2)}\right)\overline{n}\, dS$$

Application to a box



Sphere, Pinkster (1980)

2D box, Comsol (2009)



Conclusive remarks

- From years '90 the research on WECs has heen very active (about 20 devices at sea);
- The resource is abundant for the European needs, being of order 4'000 TWh/y;
- Floating WEC (3rd generation) have a low visual and environmental impact;
- Wave Energy is uncorrelated to solar and more persistent than wind energy, since it averages the wind in time and space. Wave energy is therefore complementary to other renewables;

Conclusive remarks

- Italian climate is mild. It is therefore very suited to R&D, thanks to the many periods of calm weather;
- The only economical structures are those that couple WEC to other functions:
  - REWEC3, Univ. di Catania;
  - Coastal defence, Univ. of Bologna and Padova;
- The note shows how to approach the problem of finding 2nd order forces:
  - All 5 terms forming the second order drift force are described first with reference to a single regular wave and then with reference to a sum of waves;
  - An application was presented, showing reasonable results, in quantitative agreement with asymptotic behaviors.

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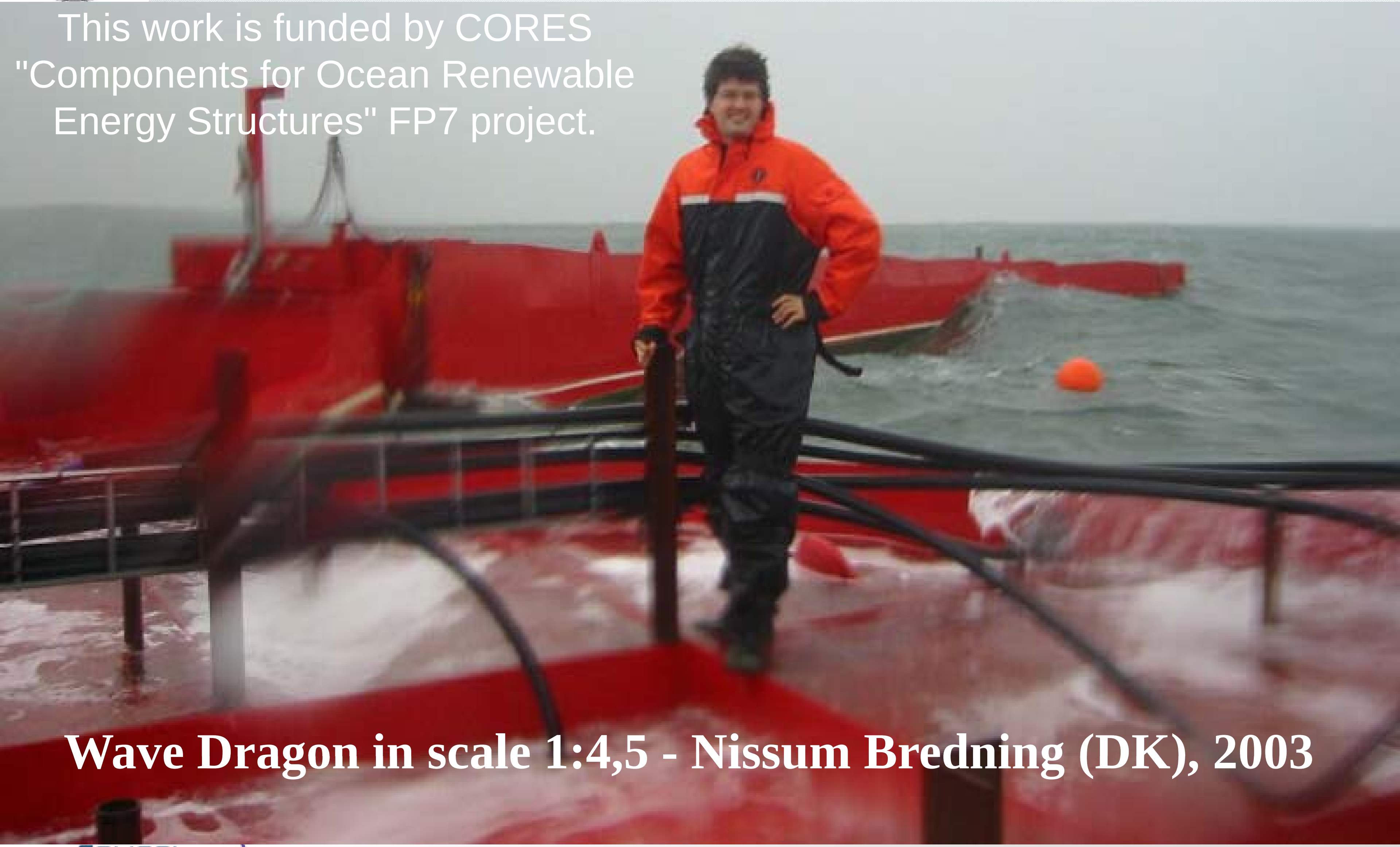

Wave Dragon in scale 1:4,5 - Nissum Bredning (DK), 2003