# EU Wavetrain2 course:
# **Ocean wave energy fundamentals**

28 June to 8 July 2010
NTNU
Trondheim, Norway

Students not interested in the details of the theory could attend only the two first days of the course to have a generic background on wave energy conversion.

It is expected that students of the course have some general knowledge of the dynamics of linear (mechanical) systems, of potential (flow) theory and of mathematical analysis including complex numbers and Fourier transform. Recommended backgrounds for the students are completed BSc, final year students for M.Sc. and Post-graduate (Ph.D.) students with relevant curricula.

**Lecturers:**
Professor Emeritus Johannes Falnes (all lectures are given by J. Falnes unless otherwise specified)
Professore Dag Myrhaug [DM]
Dr Zhen Gao [ZG]
Jørgen Hals [JH]

## Detailed course syllabus:
(an exercise list follows after the syllabus)

### Day 1 (Monday 28 June)
Lecture topics:
- Introduction; wave energy, resources and potential, examples from passed and current R&D. Simplified wave theory; orbits, propagation velocities, stored & transported wave energy.
- Different types (and classification) of wave-energy converters. Principles for primary conversion.
- Simplified example: immersed heaving body, mechanical resistance, impedance, reactance.
- Energy and power aspects: delivered/stored/ consumed, instantaneous/average, active/reactive. Optimum condition for max. absorbed wave power.

### Day 2 (Tuesday 29 June)
Lecture topics:
- Sinusoidal oscillations: phasors, complex amplitudes, complex mechanical impedance. Waves in different branches of physics: dispersion, propagation velocities.
- Stored and transported wave energy, intensity related to transported wave energy.
- Radiation resistance, impedance, reactance, and "added" mass.
- Absorption of wave energy: resonance absorption, resonance bandwidth.

### Day 3 (Wednesday 30 June)
Lecture topics:
- Practical issues: primary interface types, device survival, materials, machinery systems and their use in motion control (reactive/latching). [JH]
- Potential theory, Bernoulli's equation, Laplace equation, boundary conditions, linearisation.
- Fluid velocity in terms of velocity potential.
- Harmonic plane waves. Phase velocity and group velocity for waves propagating on water.

## Day 4 (Thursday 1 July)

Lecture topics:

- Real sea waves, shoaling, refraction and diffraction. [DM]
- Finite-height waves on deep and shallow water. [DM]
- Fourier analysis of irregular waves, measured wave spectrum, standard spectra, directional sea. [DM]
- Synthesised irregular waves [DM]
- Wave measurements and data, wave parameters derived from spectral moments. [DM]
- Wave elevation and hydrodynamic pressure in terms of velocity potential.

## Day 5 (Friday 2 July)

Lecture topics:

- Wave's stored potential energy and kinetic energy.
- Energy transport, wave-power level.
  Circular waves, far-field coefficients, far field and near field.
- Introduction to interaction between waves and a system of oscillators, immersed bodies and pressure distributions (OWCs).
- Single body interaction, six modes of motion; excitation force vector and radiation impedance matrix.

## Day 6 (Monday 5 July)

Lecture topics:

- Hydrodynamic boundary-value problem.
- Green's theorem.
- A useful surface integral taken on the totality of wave-generating surfaces.
- Waves satisfying the radiation condition.
- Proof of symmetry of radiation impedance matrix.
- Radiation resistance in terms of a far-field surface integral.
- Motion of a buoy in regular waves.
- Wave excitation and radiation forces. Resultant heave motion.

## Day 7 (Tuesday 6 July)

Lecture topics:

- Numerical results for radiation impedance and excitation force for various body geometries.
- Mooring system alternatives. Static and dynamic loads. Influence on energy absorption. [ZG]
- Reciprocity relations: Haskind relation, radiation resistance in terms of far-field coefficients and in terms of excitation-force coefficients.
- Far-field coefficients referred to local vs. global origin.
- Froude-Kriloff force and diffraction force, small-body approximation. [JH]
- Morison’s formula. [JH]
- Areas of validity of diffraction, mass and viscous forces. [JH]

## Day 8 (Wednesday 7 July)

Lecture topics:

- Linear time-invariant systems.
- Fourier transforms.
- Transfer functions and impulse response functions.
- Causal systems.
- Kramers-Kronig relations.
- An energy relation for non-sinusoidal oscillation.

## Day 9 (Thursday 8 July)

Lecture topics:

- Causal/non-causal system for hydrodynamic radiation/diffraction problem.
- Non-causal relation between hydrodynamic pressure and wave elevation just above.
- Optimum (reactive) and sub-optimum (e.g. latching) control for maximising converted power.
- Problems related to non-causality in relation to optimum control.
- Summary

## Exercise list

The following exercises will be studied during the afternoon sessions:

- 2.5: Amplitude and phase constant
- 2.6: Complex representation of harmonic oscillation
- 2.7: Superposed oscillations of the same frequency
- 2.12: Mechanical impedance and power
- 3.1: Group velocity
- 3.4: Radiation impedance for a spherical loadspeaker
- 3.5: Acoustic point absorber
- 3.7: Optimum load resistance
- 3.8: Maximum absorbed power
- 3.9: Power radiated from oscillating submerged budy
- 4.3: Vertical functions for evanescent solutions
- 4.4: Distance to wave origin
- 4.5: Reflection of plane wave at vertical wall
- 4.6: Cross waves in a wave channel
- 4.7: Kinetic energy for progressive wave
- 4.8: Kinetic energy density
- 4.9: Propagation velocities on intermediate water depth
- 4.11: Slowly varying water depth and channel width
- 4.12: Depth function $D(kh)$
- 5.2: Excitation force on surging piston in wave channel
- 5.3: Radiation resistance for vertical plate
- 5.4: Flap as wave generator
- 5.5: Pivoting vertical plate as wave generator
- 5.7: Radiation resistance in terms of far-field coefficients
- 5.11: Heave excitation force for semi-submerged sphere
- 5.12: Radiation resistance for cylindric body
- 6.1: Power absorbed by heaving buoy
- 6.2: Ratio of absorbed power to volume
- 6.3: Maximum absorbed power by axisymmetric body
- 6.4: Maximum absorbed power by symmetric 2-D body