ENE 411 - ENGINEERING LABORATORY II

WAVE ENERGY

OBJECTIVE

The objective of the experiment is to understand the physical phenomena of wave energy, the methods for converting the energy of the wave to useful energy forms, and gain the understanding of simple engineering calculations regarding wave energy.

THEORY

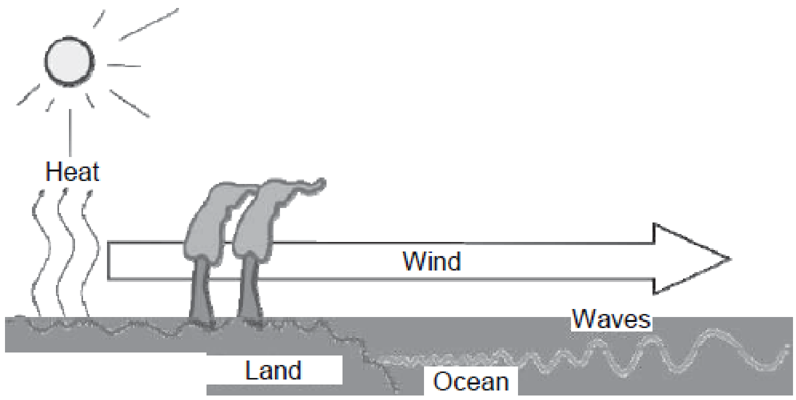


Figure 1: Mechanism of the creation of waves.

The waves are a by-product of the wind, which in itself is a by-product of solar energy. The wind creates movement in the upper layer of the water in open sea, giving an undulating form to the surface. These undulations are very small at first, then increase in size as the wind continues to blow and separate waves merge to form larger ones; there is an exchange of energy associated with this. They propagate in the form of gravity waves, with very little loss of energy, as long as the depth of the water is greater than the wavelength. Thus, waves are created in the open ocean, and the energy they contain is dissipated when they approach the coast, in shallower waters. Note that here, swell and waves are spoken synonymously; the difference between these two terms lies in the spectral typology relating to sea states (their distribution in terms of frequency and direction), but has no bearing on our argument.

The Energy Potential of a Wave

The energy transported by waves is the sum, in equal parts, of kinetic energy linked to the velocity field of water particles, and potential energy linked to the deformation of the fluid environment around its position on the surface plane. Thus, it is mechanical energy.

Wave power is defined by the flow of energy through a vertical surface perpendicular to the direction of its propagation. It could therefore be expressed in W/m^2. However, this is not the usual usage, and it is preferable to quantify wave power in W/m (watts per meter of wave front), vertically integrating the power per surface from the bottom of the ocean to the surface, thanks to the fact that the kinematic of flow at depth is known if its value at the surface is known. For infinite depth, 95% of the energy of the wave is contained in a depth equal to half its wavelength.

Wave power, expressed in watts per meter of wave front, is the flow of energy passing through a surface perpendicular to the direction of propagation of the waves per unit time. In order to determine this flow of energy, it is useful to calculate the mechanical energy of a vertical column of water which has a base of unitary surface area, and then to multiply it by the group speed of the wave. The mechanical energy of a column of water is the sum of its potential and kinetic energy. For the loss-free propagation of such a wave, it has been shown that the average value of these two types of energy are equal, and are written as follows in the case of a wave with sinusoidal deformation:

$$\langle E_{KE}(t)\rangle = \langle E_{PE}(t)\rangle = \frac{E_{ME}}{2} = \frac{\rho_w g H^2}{16} \qquad (1)$$

where E_{ME} is the mechanical energy of the wave, ρ_w is the density of seawater (which depends on the salinity, ≈ 1025 kg/m^3), g is gravity and H is the height from crest to trough of the deformation. When the depth of the water is infinite, the group speed (i.e. speed of energy propagation) is written:

$$v_g(T) = \frac{gT}{4\pi} \qquad (2)$$

where T is the period of the sinusoidal wave.

The power per meter of wave front of a sinusoidal wave is therefore equal to:

$$P_w = E_{ME} v_g = \frac{\rho_w g^2}{32\pi} H^2 T \qquad (3)$$

Equation (3) is valid for a unidirectional and sinusoidal wave.

Classification of Wave Energy Converters

There are numerous criteria which can be used to draw up classifications. The first relates to the shape of the device. Thus, we can distinguish three types of geometry:

- "Point absorbers" are axisymmetrical devices which are small in relation to the wavelength.
- "Terminators" are very large horizontally. Their main axis is perpendicular to the propagation direction of the waves.
- "Attenuators" are also horizontally large. They function in line with the direction of propagation of the waves.

A second possible means of classification relates to the location of the machines, which may be:

- "Onshore" systems are generally connected to the shore or to a manmade construction (e.g. a breakwater). They are relatively easy to maintain and to link into the electrical grid, which does not require submarine power cables to be laid. However, the available wave energy resource decreases as the depth of the water becomes less.

- “Nearshore” (between approximately 0.5 and 2 km out to sea) areas may offer the advantage of a fairly small bathymetric depth (around 1/4 of the wavelength) which enables submerged wave energy converters to be bottom-mounted, but relatively near to the shore. This characteristic enables the energy to be transported to the coast via pressurized fluid. The wave energy resource is greater than onshore, but less than in the open ocean.
- “Offshore” is, several kilometers from shore. The bathymetry at this distance is generally greater than 1/3 of the wavelength and the wave energy resource is not reduced. Transmission of the energy to shore can only be done in the form of electricity, at a voltage of around 10 kV so as to reduce line losses. It becomes essential to link the wave energy converters to one another in order to have just one submarine power cable running from the farm to the coast.

One final classification is based on the principles of hydro-mechanical conversion used by the machines. Beyond a small number of unclassifiable processes, we can thus distinguish three main types of conversion principles:

- overtopping devices: type A;
- oscillating water column (OWC): type B;
- oscillating bodies on or under the surface: type C.

Each of these principles of hydro-mechanical conversion transforms the incident wave energy into mechanical energy. This mechanical energy is null unless the mechanical movement is damped by an energy conversion system. In order to carry out this recuperative damping or braking, these principles of hydro-mechanical conversion, which are discussed in the following section, must be associated with a mechanical-electric conversion chain. We can class the principles of mechanical-electrical conversion into five categories:

Continuous rotation: The conversion can be carried out by a rotating generator with energy smoothing built into the rotating parts (type 1) or with no smoothing if the moment of inertia and speed of rotation are not great enough to store sufficient rotational kinetic energy (type 2).

Rotation or oscillatory shifting around a neutral position: The conversion can be achieved via a hydro-pneumatic or oleo-pneumatic conversion system (type 3). This means that pneumatic storage can be employed. The conversion can also be carried out directly by an electrical generator preceded by mechanical adaptation of the movement (rack and pinion transmission, gearbox, ball screw, etc.) (type 4), or simply in direct drive (type 3).

The experimental setup includes oscillating water column and oscillating water body converter systems.

Oscillating water column systems

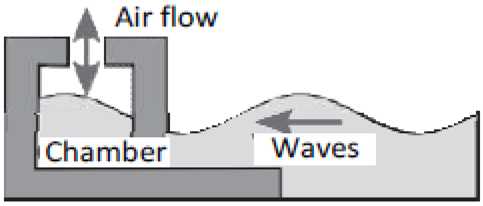


Figure 2: Principle of oscillating water column systems

Oscillating water column wave energy converters exploit changes in pressure in the air contained in a chamber (Figure 2). This chamber has a first opening which is continually submerged, so that the movements of the waves affect the column of water within the chamber. The alternating vertical movement of the internal free surface acts as a piston, creating first overpressure and then underpressure of the air trapped in the chamber. A second opening, in the open, channels the flow of air out. Thus, the air is expelled and imbibed in turn, in accordance with the natural principle of "blowholes" which can be found on some rocky coasts. Air turbines, designed so that their direction of rotation is independent of the direction of the flow of air, coupled to electrical generators convert these alternating air flows into electricity.

The chamber may be situated on the coastline (onshore) or on a floating platform (offshore). It may be built of concrete (onshore) or steel (offshore), but its shape and proportions must be optimized so as to convert the maximum amount of wave energy possible. Indeed, the movement of the column of water, which exerts a hydrostatic restoring force, is a resonating mechanical oscillation, and therefore has a natural frequency, which at the design stage, the system is adapted as much as possible to the prevailing frequency of the waves on the site.

Oscillating body systems

When an elongated floating body (such as a ship) is subject to the swell, it undergoes movements according to its 6 degrees of freedom: 3 in translation (surge, heave and sway) and 3 in rotation (pitch, roll and yaw). Surge, sway and heave respectively are the movements of translation in relation to the longitudinal axis, the transversal axis and the vertical axis. Roll, pitch and yaw are the movements of rotation in relation to the longitudinal, transversal and vertical axes respectively.

With these systems, the principle consists of using the swell to set one or more bodies in motion. The movements may be relative between two parts (internal reference, see Figure 3) or between a fixed part and a mobile part (external reference, see Figure 4). There are many technologies based on this principle. They can be classified according to the degree or degrees of freedom used. Thus, we distinguish:

- systems using one or several surging buoys;
- systems using pitch, either floating or bottom-anchored;
- systems combining heave and pitch;
- systems combining heave and yaw.

The movements obtained are slow and alternating. They are used to drive an energy conversion system which damps the movements. Owing to the low frequency of wave motion, the speeds of translation or rotation are low, and the forces needed to extract energy are very high. Mechanical energy is extracted at the speed of the waves, with no inherent means of upstream storage. Therefore, these systems are called direct wave energy converters, although this qualifier must not be confused with that which might characterize the mechanical-electrical conversion system associated with the devices, which for its part may be direct or indirect.

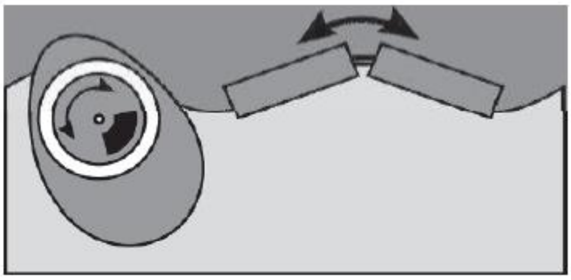


Figure 3: Oscillating systems with internal reference

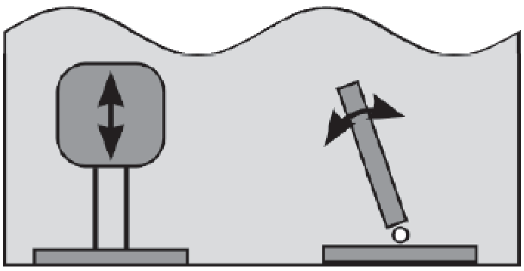


Figure 4: Oscillating systems with external reference

As regards the mechanical-electrical energy conversion system, when the force, linked to the damping of the movement or movements, is exerted by a hydro(oleo)pneumatic system, the conversion is said to be indirect (type 3). Electricity is then generated via an energy conversion system which usually includes hydraulic rams (functioning as pumps), high-pressure/low-pressure accumulators, hydraulic motors, etc. and therefore can store a certain amount of intermediary energy (in the form of pneumatic pressure).

When the electrical generator itself absorbs the mechanical movement, with no intermediary conversion stage, we speak of direct drive mechanical-electrical energy conversion (type 5). A stage of mechanical adaptation of the movement may sometimes be preferable, in order to turn linear alternating motion into rotating alternating motion (type 4). The conversion is thus no longer direct, but similar to type 5 systems, the electrical power produced still does not benefit from upstream storage of energy. The electrical power is then extracted at the speed of the waves, and thus presents the same fluctuating characteristics as the waves themselves do.

EXPERIMENTAL SETUP

Figure 5: Experimental setup

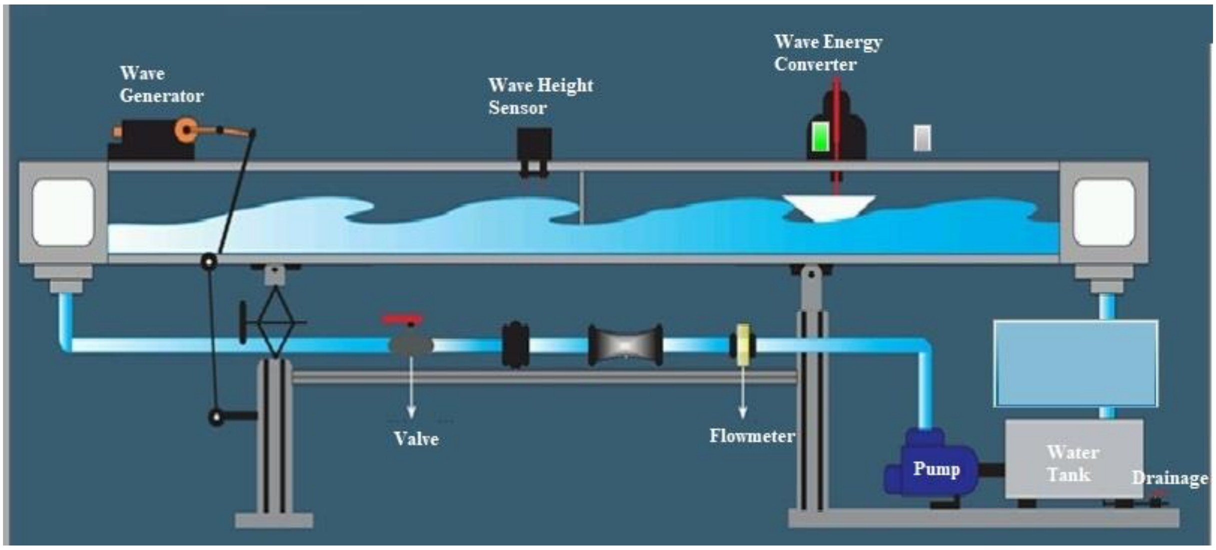
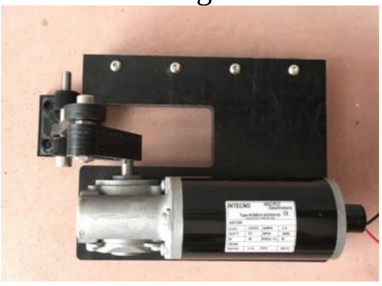


Figure 6: Wave energy experiment setup schematics

Experimental setup includes the main components such as: water tank, pump, wave generator, energy converters and several buoys with different geometries, sensors and necessary piping end electronics. Figure 5 shows the experimental setup. The main components of the system are shown schematically in Figure 6.

The components:

The wave generator

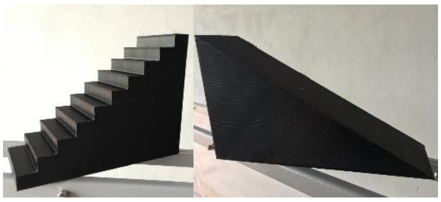


The crank connecting rod mechanism, it creates waves of different frequency and amplitude.

Flowmeter

It provides the opportunity to digitally measure the flow of the water pumped from the pump, and the flow can be increased or decreased with a ball valve.

Surface/shore shapes



The wave tank shows how different combinations of coastal defenses and wave and tidal conditions affect the potential for flooding and flood risk.

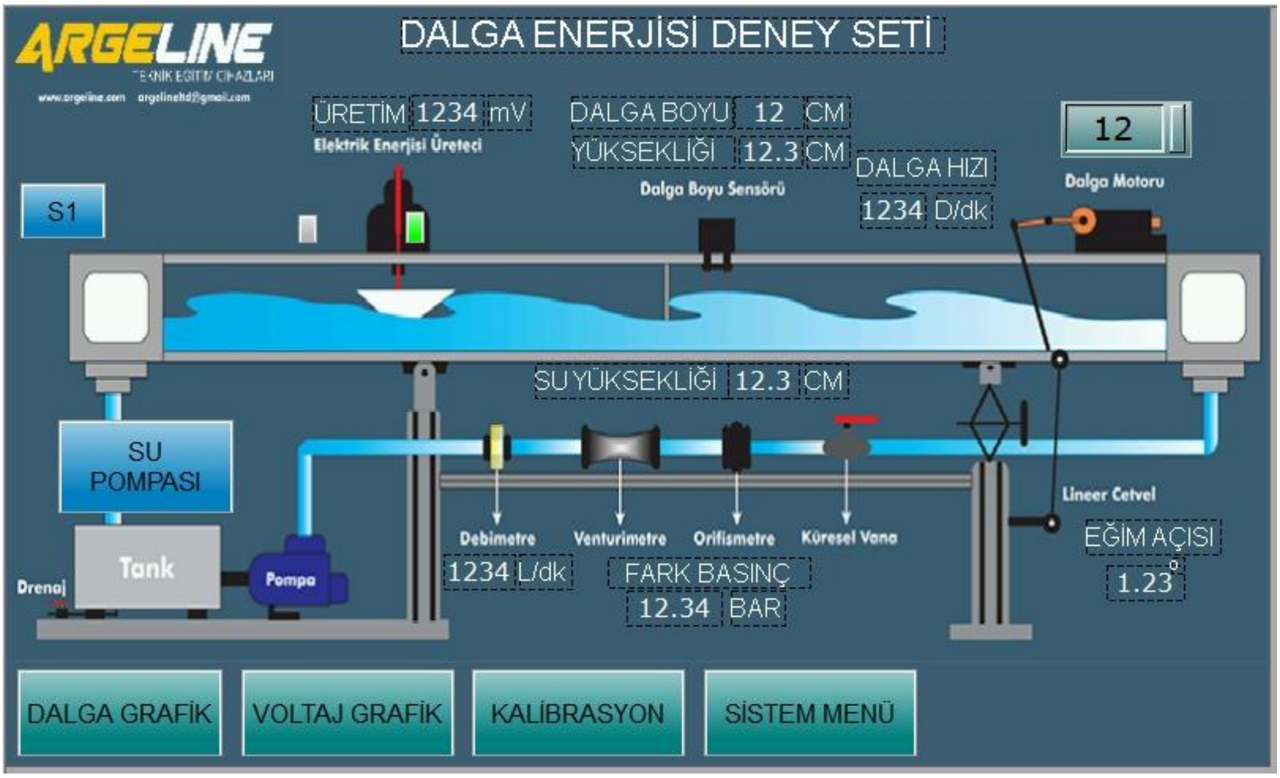
Buoys/floats for energy conversion

As a result of the linear movement of the float, energy production is seen proportionally to the magnetic field wavelength and height formed in the coil, and the wavelength and the generated energy graph may be examined on the panel screen of the experimental setup.

Energy production increases in wave types with high amplitude and wavelength.

EXPERIMENTAL PROCEDURE

Control Screen:



1. Activate the water pump to fill the device with water from the tank and the desired water level is reached by following the water height on the screen. It is recommended that the experiments be done at a water height of 16cm in order to produce a better waveform.
2. By pressing the S1 button on the LCD screen, the energy production of the buoy and the energy production of the oscillating water column by clicking again are monitored.
3. Energy production is expressed in mV
4. You can enter the value between 3 and 9 to change the wave generation.
5. Fixed water height and wavelength are displayed on the screen
6. The channel inclination angle can be adjusted with the help of the lever and the angle value can be seen on the screen
7. Wave properties and voltage are accessed from the graphic display.

MEASUREMENTS

The data is taken from the system via ethernet connection of a computer. The data include: time dependent wave height, wave length, wave velocity and produced voltage.

IN YOUR REPORT

1. Plot wave height vs time using the values given in the data sheet and determine H and T of the wave.
2. Calculate the power of the wave using v_g, H and T. Relevant constant values are either in the data sheet or given in Table 1.
3. Plot produced voltage vs time using the values given in the data sheet.
4. Calculate produced power using power of the wave and the energy converter efficiency given in Table 1.

Table 1: Given values for the calculations

Density of water	998.23 kg/m^3
Efficiency of the wave energy converter	6 %

REFERENCES

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