Energy Resources and Policy
Handout:
Wave power

1. The resource

Generated by the action of the wind, ocean waves are a very concentrated form of renewable energy, with mean power levels of many kW/m width of wave front. Its distribution around the world is not uniform, most of the energy being found in high northern and southern latitudes (Figure 1). But there are many countries with heavy energy demands, for which wave energy offers a large potential resource.

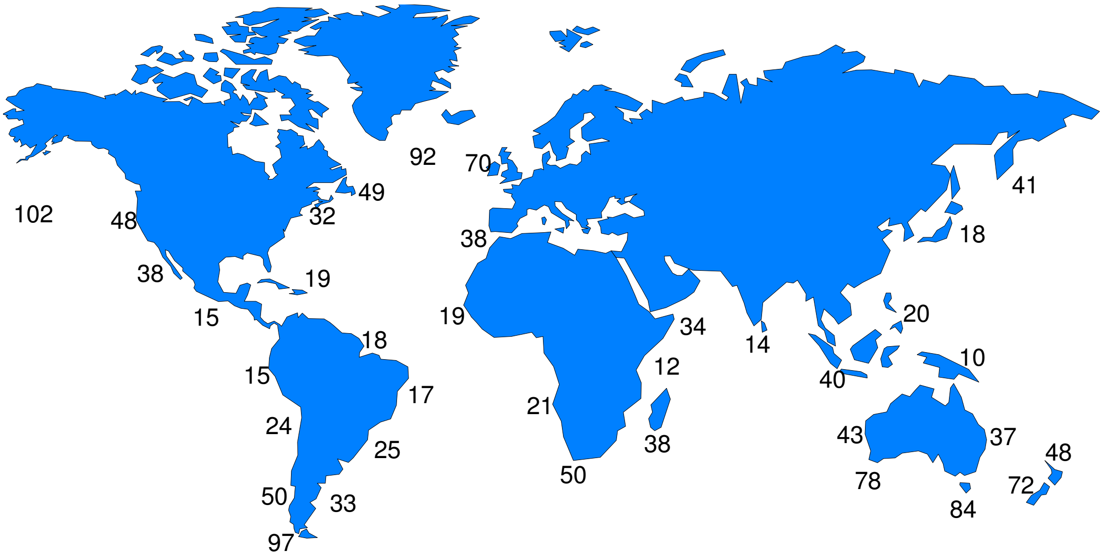

Figure 1: Annual mean power in ocean waves around the world, in kW/m of wave front.

For travelling ocean waves, the water particles move in circular orbits, the radius of the orbit decaying exponentially with depth (Figure 2). In shallow water, the orbits distort into ellipses. This particle motion is gentle, with velocities generally well below 1 m/s. The relative motion is moderate, frictional (viscous) effects are small and dissipation of energy as the wave travels along is minimal. So a surface wave is a very efficient energy carrier: energy gathered in storms is stored and transmitted over hundreds or even thousands of km. It follows that at a given site, wave energy will be more constant than the wind energy from which it is derived.

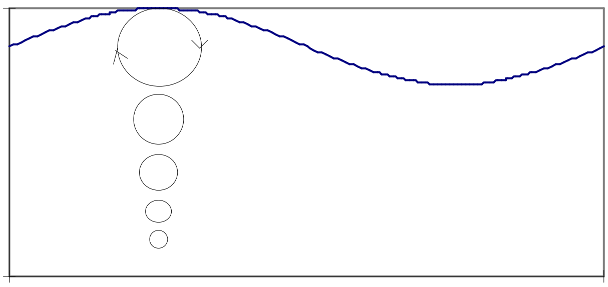

Figure 2: Orbital motion of water particles beneath a travelling wave.

Most of the analysis of wave energy conversion devices has used linear wave theory, in which the water surface profile is assumed to be sinusoidal. The period T for waves travelling past a fixed reference point is related to their wavelength λ by the equation

$$T = \sqrt{\frac{2\pi\lambda}{g}}$$

and the power, P, contained in the wave, per metre width of wave front, is given by

$$P = \frac{\rho g^2 a^2 T}{8\pi}$$

where *a* is the wave amplitude. There is no specific relationship between amplitude and wavelength.

In stormy weather, waves will reach a maximum steepness (a/λ) of about 0.03 and then break, dissipating some of their energy in the process. A similar sequence of events, steepening and then breaking, occurs as waves enter shallow water near the shore. For these conditions, linear theory is no longer appropriate.

2. Technology

Ocean wave energy conversion has fascinated inventors for centuries, and many different ideas have been put forward. A successful device must meet a number of requirements:

- it must operate reliably in a hostile, corrosive environment where frequent access for maintenance may be problematic;
- it must provide a means for efficient conversion of the low-frequency (~0.1 Hz) cyclic wave motion into a useful form (most commonly electricity);
- and it must survive the 50-year storm at its chosen site.

Extreme storms in deep water can produce waves over 30m high, with energy flows of many MW/m of wave front. Moorings for deep-water systems are a particular concern. Wave energy converters, unlike offshore oil platforms, are designed to react with the waves and will experience very large structural loads. A device may be moved into shallow water near the shore to avoid such conditions, but then the smaller waves and their directional nature significantly reduce the available mean power.

It is possible to classify wave energy conversion devices in various ways. Passive devices can be designed to guide the waves to spill over into elevated reservoirs, which then drain through conventional low-head hydraulic turbines into the sea. A number of shore-line prototypes have been constructed. Another range of devices use the waves to induce relative motion between parts of a structure. This motion can then be employed to transfer a working fluid (hydraulic oil, water or even air) around a circuit, driving a rotary machine in the process. Many different configurations have been proposed. A third category is the oscillating water column device: here, the sea water is

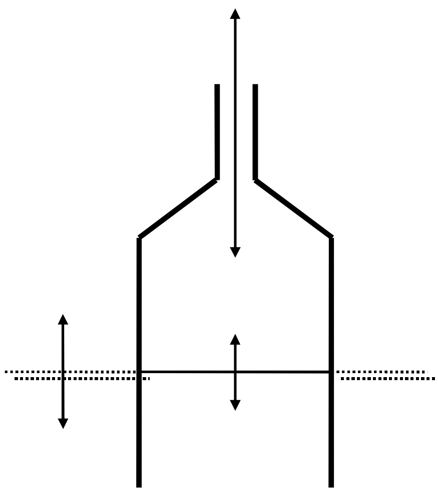

Figure 3: Oscillating water column schematic.

admitted to a chamber which is vented to the atmosphere (Figure 3).

The free surface in the chamber oscillates in response to the forcing motion of the waves, and this in turn induces a high-velocity oscillating air flow through the vent at the top, which may be used to drive a turbine and generator. An advantage of the design is that all machinery is located well above the water line.

Most of the prototypes which have appeared around the world have been based on the oscillating water column concept. In some of these, the oscillating air flow has been rectified by a system of ducting and non-return valves. More recently, the specially-developed Wells turbine has been used. This is an axial-flow device with high solidity. The aerofoils are symmetrical (Figure 4) with a high thickness-to-chord ratio which is necessary to ensure an adequate starting torque.

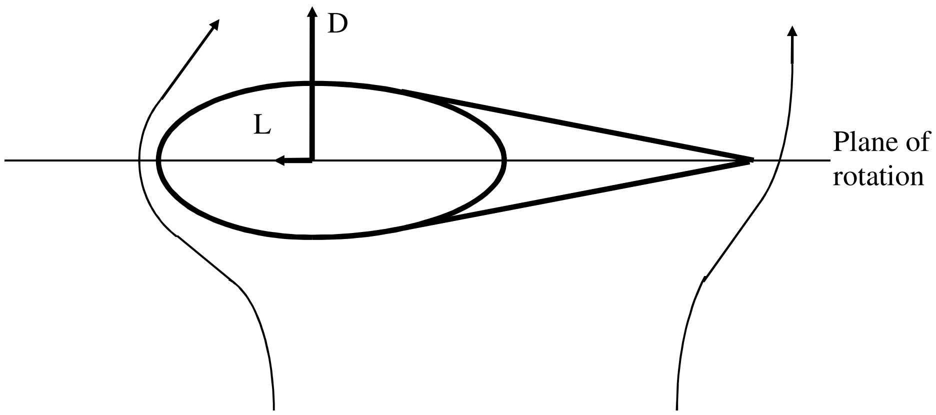

Figure 4: Section of Wells turbine aerofoil showing path of streamlines when rotor is stationary.

Deflection of the airstream past the rounded leading edge of the aerofoil produces a small but distinct lift force L. The rotor will tend to move in the same direction, regardless of the direction of flow. As the rotor speeds up, aerodynamic efficiency improves, but is never more than moderate (about 70% in the laboratory, 50 to 60% in real waves), and future designs may include guide vanes or variable-pitch blading, departing from the simplicity of the original concept.

3. Exploitation

The most significant events are listed below.

1965 Japan	Wave-powered navigation beacon developed by Masuda. 50W oscillating water column (OWC) device. Several hundred constructed and deployed around Japanese coastline.
1985 Norway	Two prototypes constructed: a 500 kW OWC and a 350 kW passive device. Performance matched expectations. OWC destroyed in storm in 1988.
1985 Scotland	Prototype 75 kW OWC device constructed at shoreline site on Islay. Satisfactory operation; decommissioned 1999.
1995 Scotland	Osprey 2 MW prototype OWC constructed. Device damaged by storm during installation and removed from site. Replacement planned but abandoned due to unforeseen problems with site.

1998	Two 500 kW OWC shoreline installations given clearance to proceed with EC research funding. Locations Islay, Scotland and Pico, in the Azores. Both commissioned in 2001 – 02.
2003 Scotland	Construction of full-scale 750 kW Pelamis prototype for trial deployment at Orkney test centre.
2004 Europe	Sea trials of Archimedes Wave Swing off Portugal and Wave Dragon over-topping device in Danish waters.
2006 Portugal	Agreement for first wave energy 'farm' using Pelamis machines.

High fossil fuel prices and concerns over security of supply are causing a resurgence of interest in wave energy. New projects and prototypes are presently appearing in many parts of the world.

4. Environmental impact

Offshore (deep water) devices will have no great visual impact, and their effect on marine ecosystems, coastal currents and wave climates are likely to be small. Their ability to create sheltered zones should not be relied upon, for in storm conditions they would be designed to allow most of the approaching energy to pass by in order to survive. They might be a hazard to shipping, and to fishing activities. If large quantities of power are produced, the visual impact of electrical transmission lines in coastal regions may be a concern.

Coastline or shallow-water devices could interfere with recreational activities, will have some visual impact and may generate noise. They may also have an unwelcome impact on local wildlife.

5. Conclusions

Ocean wave energy is a major resource in global terms, but its exploitation presents an engineering challenge which has not yet been overcome. Many fundamentally different devices have been proposed, and the correct path to follow is still not clear. Demonstration systems in shallow water, where operating conditions are comparatively benign, have been appearing in many parts of the world. But the production of significant amounts of energy requires a move offshore into deeper waters. The success of devices designed for this purpose, such as Pelamis, is crucial to future large-scale exploitation.

Costs during the early stages of development cannot possibly compete with conventional sources, and must be subsidised if an industry is to grow. Analogies with the wind industry are relevant here. Production of wave energy is likely to be far from demand centres, so reinforcement of the electricity grid will generally be required and transmission costs will be substantial.