Hydrodynamics of Wave Power Extraction

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BACKGROUND

- Rising the demand for energy as well as the cost of conventional forms of energy, mainly fossil fuels, and desire to mitigate the impact of fossil fuel emissions necessitate studying and investing in clean renewable sources of energy such as solar, wind, biofuels, geothermal, tidal, and wave energy

- The potential benefit of tapping wave energy resources in our mix of generation options for the future is significant

- It is believed that wave energy, which is currently at the early stage of R&D, will soon become commercially competitive with the current wind and solar technology in many parts of the world

ADVANTAGES OF WAVE ENERGY

- According to the world energy council, about twice the world's electricity production needs could be extracted from oceans so there is a significant potential

- Availability along many coasts of the world considering the fact that half of the world's population lives in coastal regions

- Predictability and intermittency of waves are two important factors in dispatch and storage of energy

- Wave energy has a much higher power intensity than solar, wind or even tidal energy, making it easier and cheaper to harvest

- Wave-energy devices generally have a very low profile and located far away from the shoreline, making them essentially invisible

- Converting ocean wave energy is considered to be one of the most environmentally friendly ways to generate electricity

ENVIRONMENTAL CONSIDERATIONS

- Wave-energy farms near the shore may protect shorelines against storm surges and coastal erosion

- Providing shelter for marine life

- They are not visually intrusive on the seascape

- Depending on the type of devices, leakage and underwater or atmospheric noise might be a problem

ECONOMIC POTENTIAL

- Current market is small but has a substantial potential to grow and meet a significant portion of world's electricity demand

- The World Energy Council estimates that wave energy could reach 2 billion kW, more than half of the world electricity installed capacity

- Cost of wave energy has been reduced significantly over the past two decades

OCEAN SURFACE WAVES

- Ocean surface waves are simply energy in transition

- Wind-generated waves are actually a form of solar energy since the primary source of wind energy is the sun

- In each transformation of energy, solar to wind, wind to wave, power intensity increases

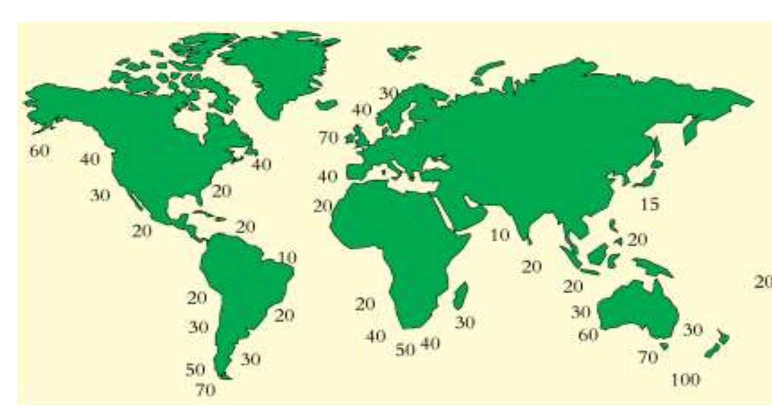
Average solar insolation at a latitude of 15ºN	0.17 kW/m^2
Power intensity of wind (10 m/sec) at the same latitude	0.58 kW/m^2
Power intensity of average wave generated by this wind	8.42 kW/m^2

- Wave energy extraction refers to changing of wave energy into mechanical motion which in turn can be converted into electricity

- The power flux within unit crest length of a plane wave in deep water is proportional to the wave period and to the square of the wave height

Wave height	*Wave period*	*Power flux rate*
A=1 m (gentle waves)	T=10 sec	40 kW/m
A=5 m (large waves)	T=10 sec	1000 kW/m

- Wave energy levels, unlike wind, are well-documented on a global scale



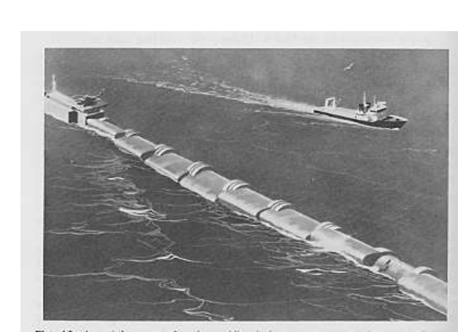
World-wide estimate of wave energy in kW/m of coastline.
By T. Thorpe 2005

WAVE-POWER DEVICES

Wave-power devices can be categorized according to their geometric configurations

- *Beam-sea absorbers*

A long line of 2-D cams hinged on a horizontal axis near the sea surface and parallel to the shore; energy extracted from the rolling motion of the cam



- *Point absorbers*

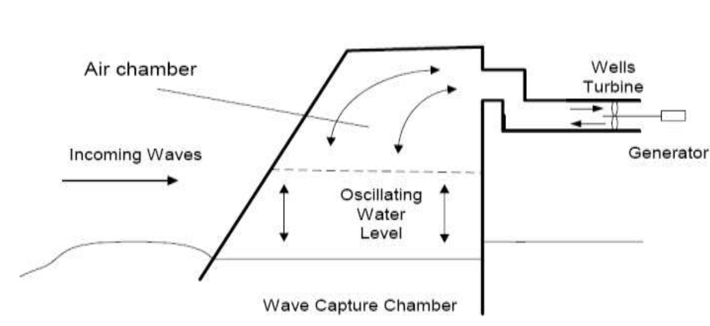
A simple buoy floating on the sea surface and insensitive to the direction of incoming waves; energy can be extracted from three modes of oscillation

- *Head-sea absorbers*

A series of long rafts, hinged to form a long snake, moored at one end and is naturally aligned with the direction of incoming waves; energy can be extracted at the hinges from differential angular oscillations of the rafts

- *Oscillating water column*

Consists of a chamber with an opening at the bottom; water enters and retreats from the chamber cyclically and pushing air up and down in the upper chamber which can rotate a turbine



TECHNICAL CHALLENGES

From the mechanical side

- All current designs are based on linear concepts of resonance, at or close to one frequency; sea waves are however nonlinear and random with a broad range of frequencies and directions

- At any site, the wave climate is never steady; daily to seasonal variation is large

- The system must be able not only to survive but also to operate safely in hostile weather such as hurricanes, which cause highly nonlinear waves

- To achieve the capacity of a conventional power plant, it is necessary to install an array of many energy absorbers; hydrodynamic interaction within the array comes into play

RESEARCH OBJECTIVES

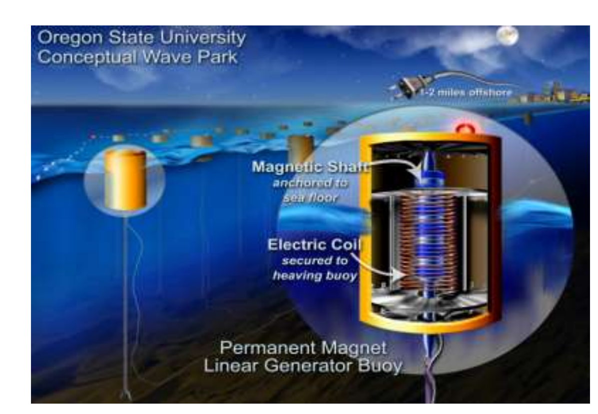
Addressing some of the major technical challenges, we will develop theories to predict the hydrodynamic aspects of two most economical types of wave-energy absorbers (buoys and oscillating water columns) in the following areas

- Nonlinearity of waves and absorber motion

- Energy loss in the neighborhood of absorbers

- Randomness of waves

- Mutual interaction of neighboring absorbers in a wave farm, which is an array of many point absorbers

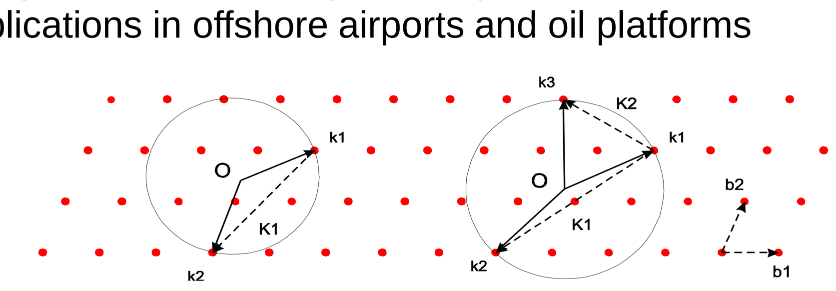


Conceptual array of wave power buoys

RESEARCH PLANS

Focusing on the extraction of mechanical energy from sea waves, without including the specifics of mechanical to electrical energy conversion, with the ultimate goal of predicting wave power absorption rate, wave forces on and motion of absorbers

- Employing certain general tools in solid-state physics and crystallography for waves in periodic medium to develop a theory for scattering of water waves by an array of fixed scatterers which also has applications in offshore airports and oil platforms



Method of *Ewald Construction* in *crystallography* to find the direction of resonantly scattered waves from the *reciprocal lattice*

- Extending the theory to incorporate energy dissipation around the scatterers to model wave farms with fixed absorbers

- Extending the theory to floating wave-absorber arrays which are no longer stationary and can absorb as well as radiate waves

- Investigating the effect of variation of sea depth which refract waves

- Developing theories for broad-banded random incident waves