UMP OPEN COURSEWARE

Universiti Malaysia PAHANG

BMM4753 RENEWABLE ENERGY RESOURCES

Chapter 8. Ocean Wave Energy

Prof Dr Shahrani Haji Anuar

Energy Sustainability Focus Group

Summary

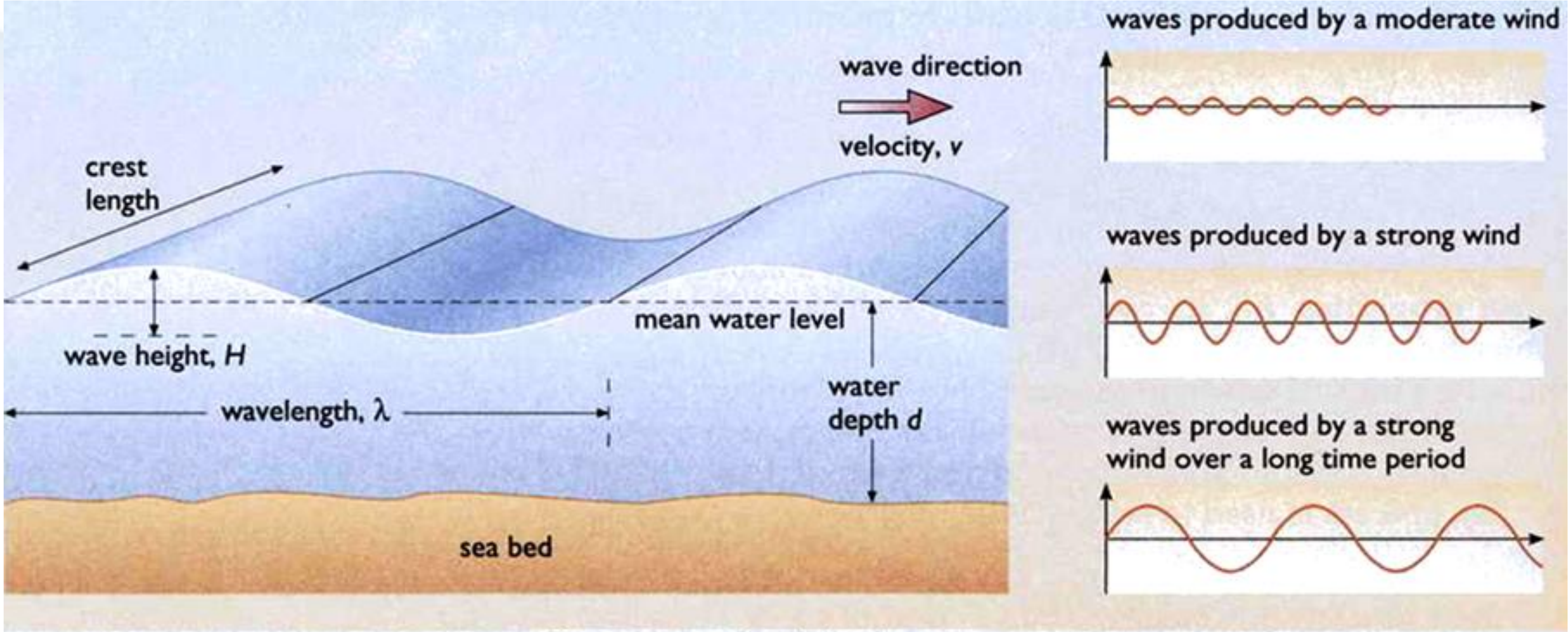
8.1 Introduction

The ocean is a big collector of energy transferred by wind over a large surface area which is stored as wave energy. Wave energy is more concentrated compared to wind energy, which is thinly distributed. Wave energy is available in coastal areas, islands and its potential depends upon its geographic location. Energy available in ocean waves varies in different months and seasons. Wave energy, if harnessed with improved technology, can prove to be a large dependable source of renewable energy. A host of devices are being invented to harness the power of the waves. The potential of tidal power is more limited but predictable while wave power offers a greater resource but is more erratic and dependent on wind and weather systems. Worldwide, economically recoverable wave energy resource is in the range of 140 to 750x10^{12} W/yr for existing wave capturing technologies.

8.2 Characteristics and formation of waves

- Ocean Wave Energy refers to the waves of water from ocean to the shore. Ocean waves occur due to the rotation of earth and the winds over ocean surface.
- Wind makes wave, generated by uneven solar heating of atmospheric air and the rotation of the earth.
- Moving air cause water molecules on the surface to travel in the same direction as the wind. Molecules of water move, collide with others and set them in motion and waves are formed.
- Waves formed due to storms can travel large distance and retain much of the energy of the original storm waves in deep waters.
- The energy dissipates when it reaches waters, less than 200 m deep.
- Waves have an interval of 4 to 12 seconds and crest of a few centimeters to about 10 m. Locations having waves with crest height of 3 m and above have higher energy density.

8.2 Characteristics and formation of waves

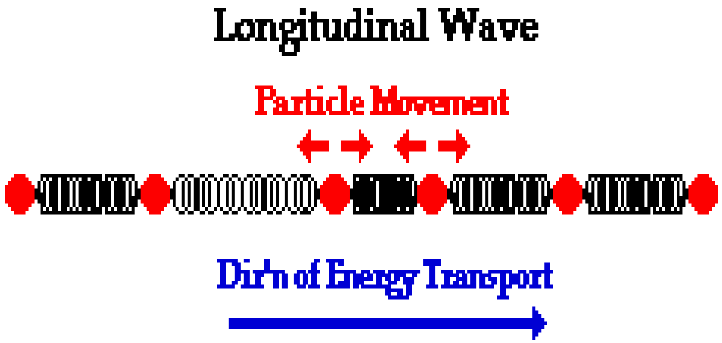


Characteristics of an idealized wave

8.2 Characteristics and formation of waves – Types of waves

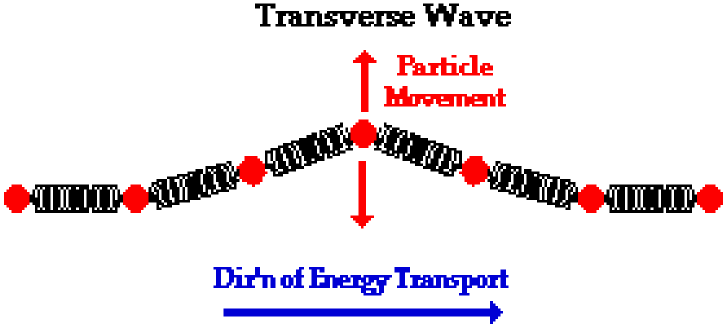
Longitudinal

A wave in which particles of the medium move in a direction parallel to the direction which the wave moves.



Transverse

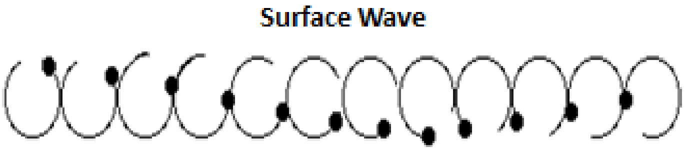
A wave in which particles of the medium move in a direction perpendicular to the direction which the wave moves.



8.2 Characteristics and formation of waves

Surface Waves

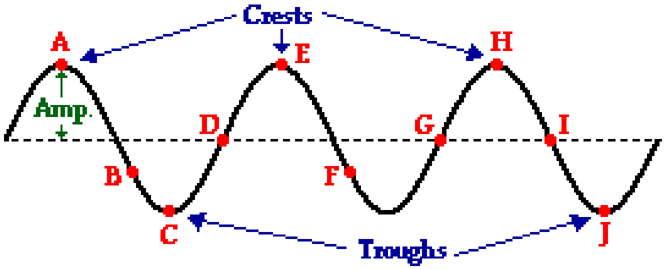
- Travel along the surface of the oceans in which particles of the medium undergo a circular motion.
- Surface waves are neither longitudinal nor transverse.



A surface wave is sometimes referred to as a circular wave since particles of the medium undergo a motion in a complete

Amplitude

- Maximum displacement of a particle on the medium from its rest position.
- Distance from rest to crest.



8.2 Characteristics and formation of waves – Affecting Factors

There are 3 major factors governing the quantum of wave energy:-

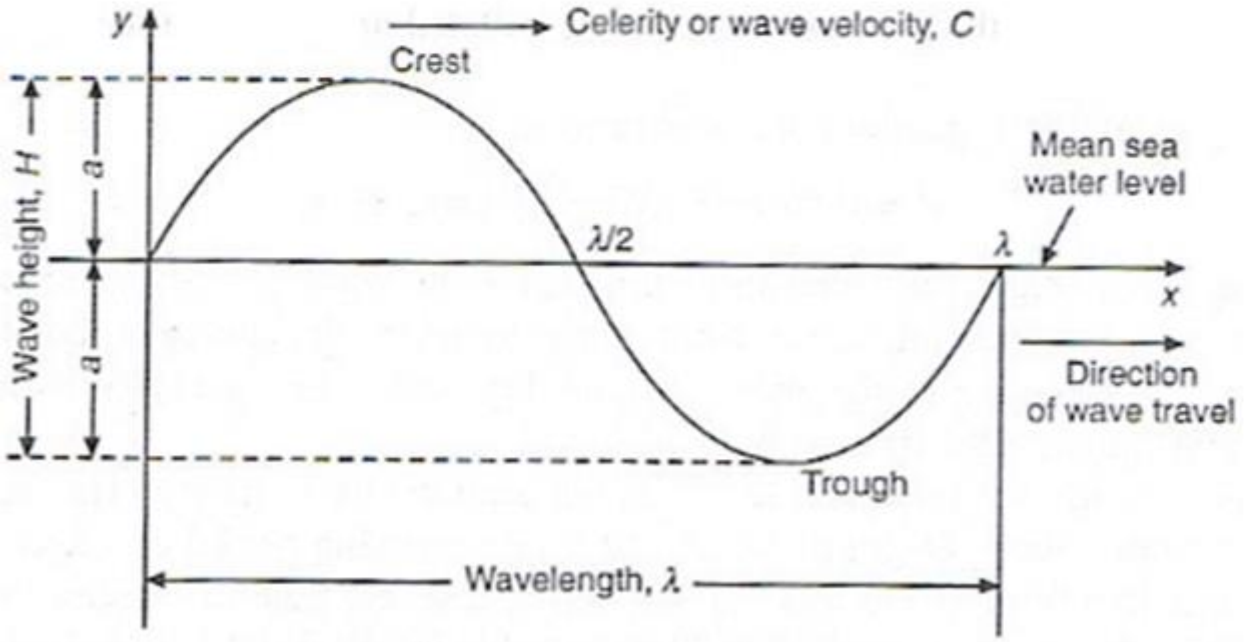
Wind Speed The higher the wind speed, the higher is the wave energy. The amplitude of the waves depends on the wind speed. During gusts and storms big ocean waves occur, which prove dangerous even to ships.

Effective Fetch Value The uninterrupted distance on the ocean over which the wind can blow before reaching the point of reference. The larger the distance, the higher the wave energy. This distance may vary from 5 km to 45 km.

Depth of the Sea Water The greater the depth of ocean water, the higher the wave velocity. Very large energy fluxes are available in deep ocean waves.

8.2 Characteristics and formation of waves – Affecting Factors

Ocean Wave Parameters



Representative ocean wave.

8.2 Characteristics and formation of waves – Affecting Factors

Ocean Wave Parameters

The periodic up and down, to and fro motion of water in seas and oceans is known as 'ocean wave'. The important wave parameters are:-

H = wave height. It is the distance from the trough to the crest (not to the height above sea level). It mainly depends on wind speed and the fetch. The value varies from 0.2 m to 3 m.

a = amplitude of the wave = $\frac{1}{2}H$

λ = wavelength

T = wave period which usually ranges from 4 s to 12 s

f = frequency expressed as the number of periods per second.

As a progressive wave moves, the crest line travels in; J horizontal plane with a wave velocity or celerity C (wave velocity) in the direction of the x-axis, which also represents the mean sea-water level.

8.2 Characteristics and formation of waves – Affecting Factors

Ocean Wave Parameters

The frequency *f* is defined as the number of troughs or crests passing per second through a given point in the direction of wave motion.
The wavelength *λ* is the horizontal distance between two successive troughs or crests.

Wave velocity or celerity	$C = \frac{\lambda}{T}$ m/s
Period	$T = \frac{1}{f}$ s^{-1}
Wavelength	$\lambda = 1.56\,T^2$

8.2 Characteristics and formation of waves – Affecting Factors

Energy from High Wave

High waves are generated in deep ocean areas. As the train of waves approaches the shore, the wave period necessarily remains constant, but the wavelength, the celerity and the wave height undergo changes. As the wave approaches shallow waters (breaker zone), the decreasing depth of water gives rise to bed friction, here a part of the wave energy is dissipated in overcoming the frictional force. In this process the wave gets distorted. The water particles which have closed orbits in deeper water, now start moving forward with the wave. Consequently, when the depth of water decreases to a value nearly equal to 1.3 times the local wave height, the crest plunges forward and the wave breaks dissipating its energy on the shore.

8.2 Characteristics and formation of waves – Affecting Factors

Energy from High Wave

Wave energy is defined as the rate at which it is transferred across one meter line at right angles to its direction. Energy available in random sea,

$$P = 0.96\, H^2 T \text{ kW/m of wave crest}$$

where, *H* = wave height measured in m

T = wave period in seconds

- ☐ The wave energy potential varies from place to place depending upon its geographic location. Even at a given place, the energy availability varies during the different parts of the day, for different months and from season to season.

8.2 Characteristics and formation of waves – Affecting Factors

Energy from High Wave

- ☐ Waves in ocean are not regular sine waves but are random in nature.
- ☐ This indicates that a wave condition with a wave height of 1.5 m and a zero crossing period of 7 seconds possesses a power of about 15 kW/m of the wave crest.
- ☐ During a severe gale, the ocean fluxes could be as high as 1000 kW/m of wave crest.
- ☐ During the protracted calm or in sheltered inlets, the power could be as little as 0.001 kW/m.

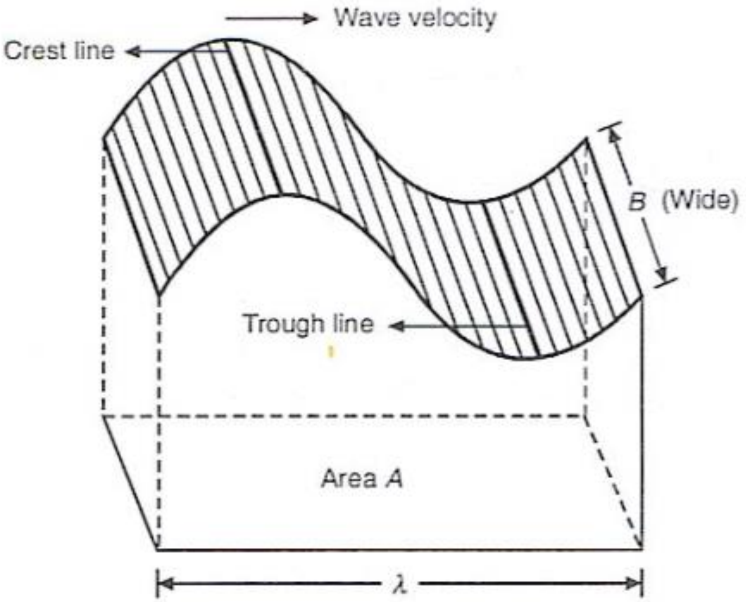
8.3 Mathematical Analysis and Empirical Formula

Maximum concentration of wave energy is available between the latitudes 25° and 55° in both the hemispheres. Latitudes of around 30° are most suitable for harnessing wave energy. There is low pressure about the equator and high pressure near the tropics. So, trade winds blow from the sub-tropical belts towards the equator and create wave energy potential.

Winds blowing over long distances on Atlantic and Pacific Oceans generate high waves with peaks of about 50 meters between crests, displacing enormous quantity of water in each wave. The open west coasts of United States, Europe, Japan, Australia and New Zealand are the attractive sites for exploitation of wave energy.

8.3 Mathematical Analysis and Empirical Formula

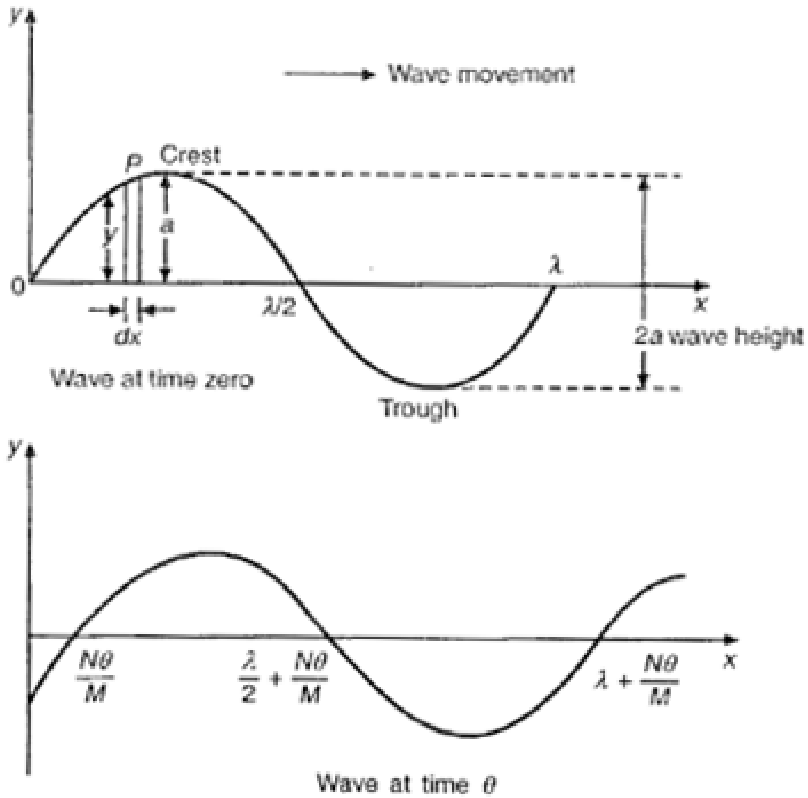
- Ocean wave is a moving sheet of energy with a certain large breadth *B*, and a standard length equal to wavelength λ.
- Energy density and power density of the wave is dependent on wave area.
- Wave area is the projection on a horizontal plane of one full wave having width *B* and length equal to the wave length λ.
- Total content of the wave energy *E* is proportional to the area *A*.



Water wave width B and length λ ($B >> \lambda$)

8.3 Mathematical Analysis and Empirical Formula

- A progressive water wave can be represented by a sine curve.
- Sea waves are highly irregular but may be assumed to be of sinusoidal harmonic wave shape for the purpose of mathematical analysis.
- The wave is moving in the direction of the x-axis, 2*a* is the height of the wave from crest to trough in the direction of y-axis i.e. the amplitude is *a.*



Two-dimensional progressive wave at time zero and time θ.

8.3 Mathematical Analysis and Empirical Formula

Let there be a point *P* on the wave surface with an element of thickness *dx* along the x-axis with a coordinate *y* on the y-axis. The wave being sinusoidal the value of coordinate *y* can be expressed with the following equation,

$$y = a\sin\left[\frac{2\pi x}{\lambda} - \frac{2\pi\theta}{T}\right]$$

where the coordinates of point *P* is *(x, y),* and

a = wave amplitude, in meter
λ = wavelength, in meter
Θ = time, in second
T = wave period

For particular wave, $\frac{2\pi}{\lambda} = M$ and $\frac{2\pi}{T} = N \rightarrow y = a\sin(Mx - N\theta)$

$$(Mx - Nt) = 2\pi\left(\frac{x}{\lambda} - \frac{\theta}{T}\right) = \text{phase angle, dimensionless}$$

8.3 Mathematical Analysis and Empirical Formula

Total Energy in water wave is the sum of **potential** and **kinetic** energies.

Potential energy of elevated water is equal the work to be done in raising that much quantity of water to the elevated height,

Work done = Force x Distance = mgh joules

where m is the mass of the elevated water in kg, h is the height in metres to which the water is elevated, g is acceleration due to gravity in m/s^2.

m = mass of water element dx = ydx x B x p with wave width B

$h = y/2$

□ = water density, in kg/m^3

Therefore,

Work done = ydx x B x P x $(y/2)$ x g

Potential energy = ½g □ y^2 Bdx

8.3 Mathematical Analysis and Empirical Formula

Substituting the value of *y* and integrating from θ to λ for wave area $(\lambda \times B)$

Potential Energy $PE = \frac{1}{2} g\rho B \int_0^\lambda a^2 \sin^2(Mx - Nt)dx$

$$= \frac{g\rho B a^2}{2}\left(\frac{1}{2}x - \frac{1}{4M}\sin 2Mx\right)_n^\lambda = \frac{1}{4} g\rho B a^2 \lambda$$

Wave area
$A = B\lambda$

Potential Energy density $= PE/A = \frac{1}{4}\frac{g}{g_c}\rho a^2$

Conversion factor
$g_c = 1.0 \ kg/m/Ns^2$

8.3 Mathematical Analysis and Empirical Formula

Kinetic Energy Due to blowing of wind on the surface of ocean, water waves moving over the ocean surface are fast. Due to their high speed, the ocean waves have a lot of kinetic energy.

When the amplitude *a* of the wave is small compared to its wavelength, then the potential energy and the kinetic energy are equal. Kinetic energy of the wave,

$$KE = \frac{1}{4} g\rho B a^2 \lambda \longleftarrow$$

Wave area
$A = B\lambda$

Kinetic energy density of the wave,

$$\frac{KE}{A} = \frac{1}{4} g\rho a^2$$

8.3 Mathematical Analysis and Empirical Formula

Total Energy is the total energy contained in the ocean wave having wavelength λ, period *T* and breadth *B* is the arithmetic sum of potential and kinetic energies

$$E = PE + KE = \frac{1}{4} g\rho B a^2 \lambda + \frac{1}{4} g\rho B a^2 \lambda = \frac{1}{2} g\rho B a^2 \lambda \quad (J)$$

Energy density becomes,

$$\frac{E}{A} = \frac{1}{2} g\rho a^2 \quad (J/m)$$

Wave power Total energy per unit time

$$Power = \frac{Total\ Energy}{Time} = E \times f = \frac{1}{2} g\rho B a^2 \lambda f$$

Power density $= \frac{P}{A} = \frac{1}{2} g\rho a^2 f \quad (W/m^2)$

8.3 Mathematical Analysis and Empirical Formula

Wave energy is derived from wind energy. The higher the wind speed over the sea surface, the higher the wave height and the wave energy .

Scripps Formula The Scripps Institution of Oceanography in La Jolla California proposed a relationship between wave height and wind velocity as,

$$H = 0.085U^2$$

where H = wave height in m, and

U = wind speed in knots (1 knot = 1.4 km/h)

8.3 Mathematical Analysis and Empirical Formula

Zuider Zee Formula It combines five variables, namely the wind speed, the fetch, the rise of water level, the water depth and the angle between the wind direction and the fetch,

$$H = \frac{KV^2F\cos a}{D}$$

where,

H = rise in water level above the normal, in m
K = 6.08 X 10^{-3} (constant)
F = fetch, i.e. unobstructed largest dimension of the lake, in m
V = wind speed, in km/h
D = average water depth, in m
a = angle between the wind direction and the fetch

8.4 Wave Energy Resources

Waves with an amplitude of 2 m and period of 10 s are of considerable interest for power generation with energy fluxes averaging between 50 and 70 kW per meter width of the oncoming wave. Wave energy can be better concentrated than the solar energy. Devices that convert energy from waves can therefore produce much higher power densities than those produced by solar devices.

Ocean wave energy is primary energy and the approach is to convert it into usable secondary energy. The selected site must have good wave power potential, easy access to deep water, away from cyclonic zone and nearness to the available infrastructural facilities.

Breakwater is constructed which checks the erosion of the coast. Wave energy installation and anti-erosion works are complimentary and in totality economically viable.

8.4 Wave Energy Resources

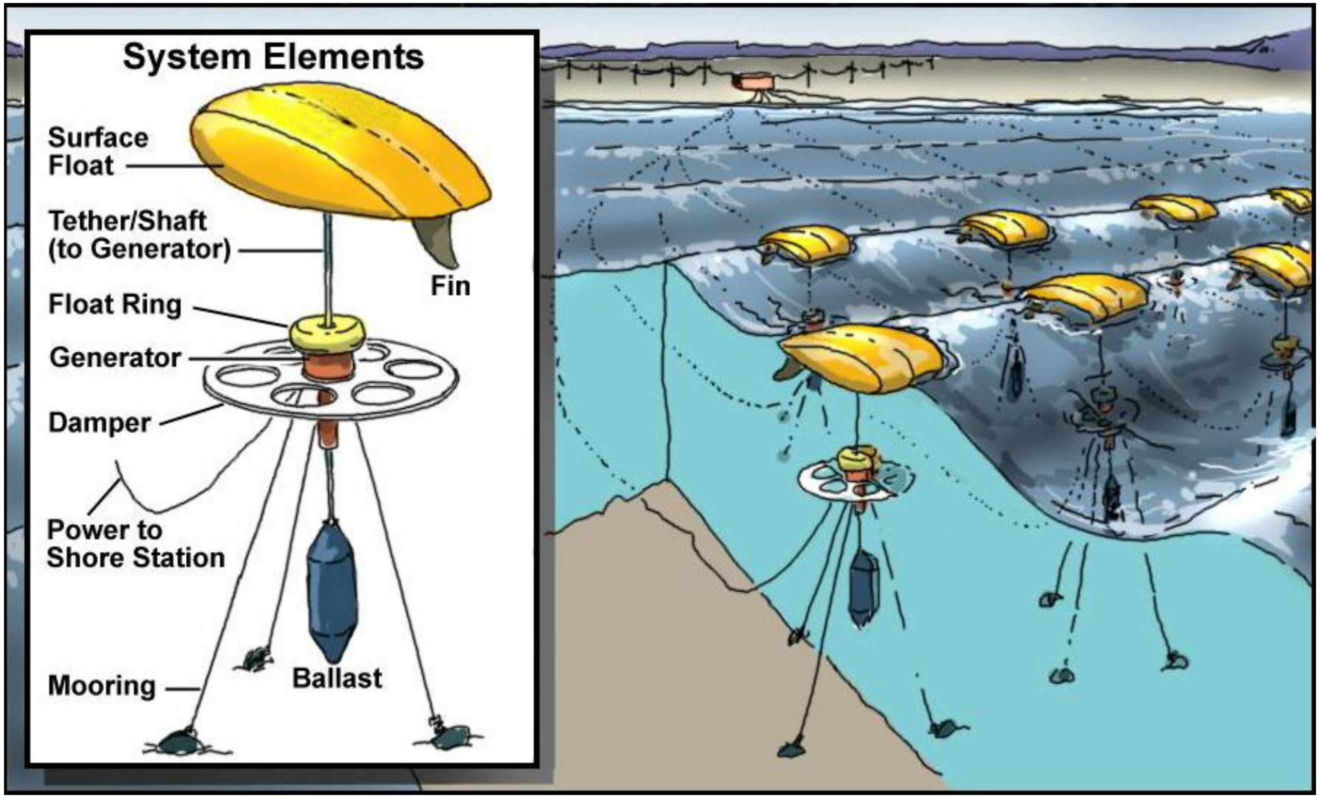
- ❑ **Potential of 1,500 – 7,500 TWh/year**
  - 10 and 50% of the world’s yearly electricity demand
  - IEA (International Energy Agency)
- ❑ **200,000 MW installed wave/tidal energy power by 2050**
  - Power production of 6 TWh/y
  - Load factor of 0.35
  - DTI and Carbon Trust (UK)
- ❑ **Independent of the different estimates the potential for a pollution free energy generation is enormous**

8.4 Wave Energy Resources

Average wave energy in kW/m (kW per meter of wave length)

8.5 Wave Energy Technologies

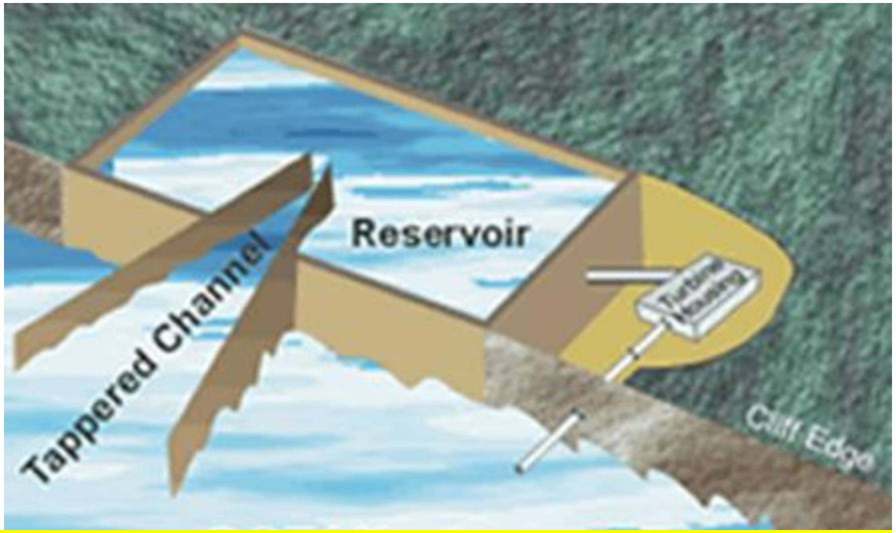
1) Terminators 2) Attenuators 3) Point absorbers 4) Overtopping devices



8.5 Wave Energy Technologies – Terminators

Tapered Channel (TAPCHAN) – hydroelectric

- Wave travels down the narrowing channel and increases in height, water spills into an elevated reservoir
- Water trapped in the reservoir is released back to the sea similar to conventional hydroelectric
- Advantage, ability to buffer storage and dampens the wave irregularity



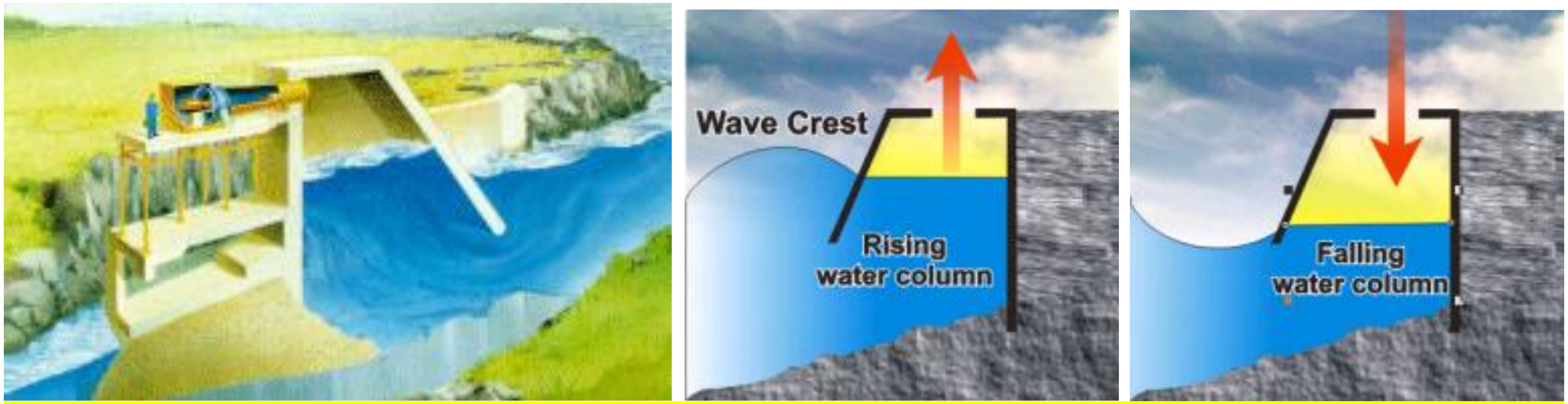
Tapered Channel (Tapchan) – conventional hydro

- Require a low tidal range and suitable shoreline topography thus limiting its application world-wide.
- Prototype design has been running since 1985 and plans are under consideration to build a commercial scale plant in Java.

8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)

- Wave enters the column, forcing the air in the column up the closed column past a turbine
- As the wave retreats, the air is drawn back past the turbine due to the reduced air pressure on the ocean side of turbine.

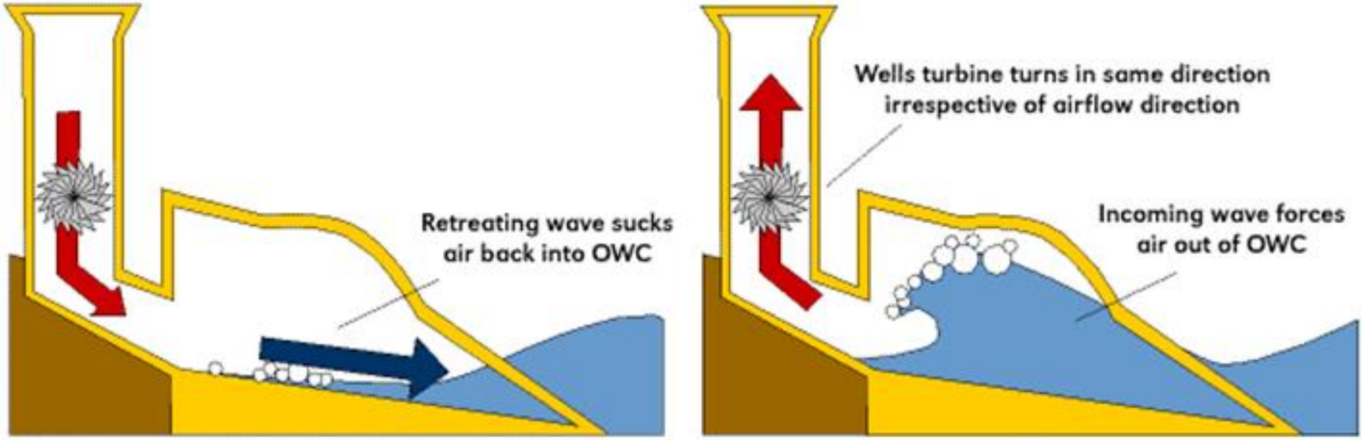


Oscillating Water Column

8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)

- ❑ Extend perpendicular to the direction of wave travel and capture the power of the wave.
- ❑ Wave action causes the captured water column to move up and down like a piston to force the air through an opening connected to a turbine.



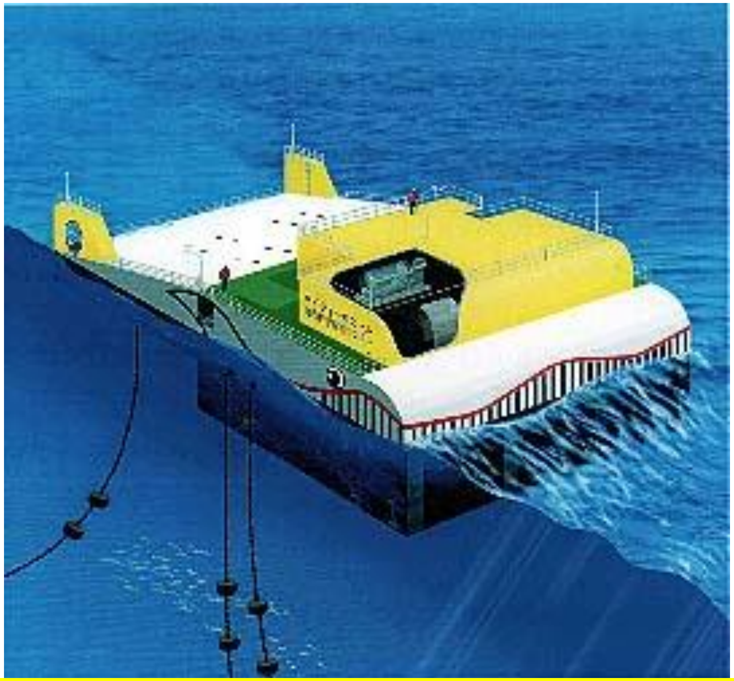
8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)

- ❑ Land Installed Marine Powered Energy Transformer (LIMPET) is a shoreline energy converter sited on the island of Islay, off Scotland's west coast in the year 2000, producing power for the national grid.
- ❑ A 500 kW prototype OWC designed and built by Energetech (2006) is undergoing testing offshore at Port Kembla in Australia.
- ❑ Design, performance and cost assessment for a 1000 kW rated capacity with multiple units is being planned by Energetech to be sited 22 km from California coast.
- ❑ "Mighty Whale" an offshore floating prototype is under development in Japan since 1987 (JAMSTC 2006)

8.5 Wave Energy Technologies – Terminators

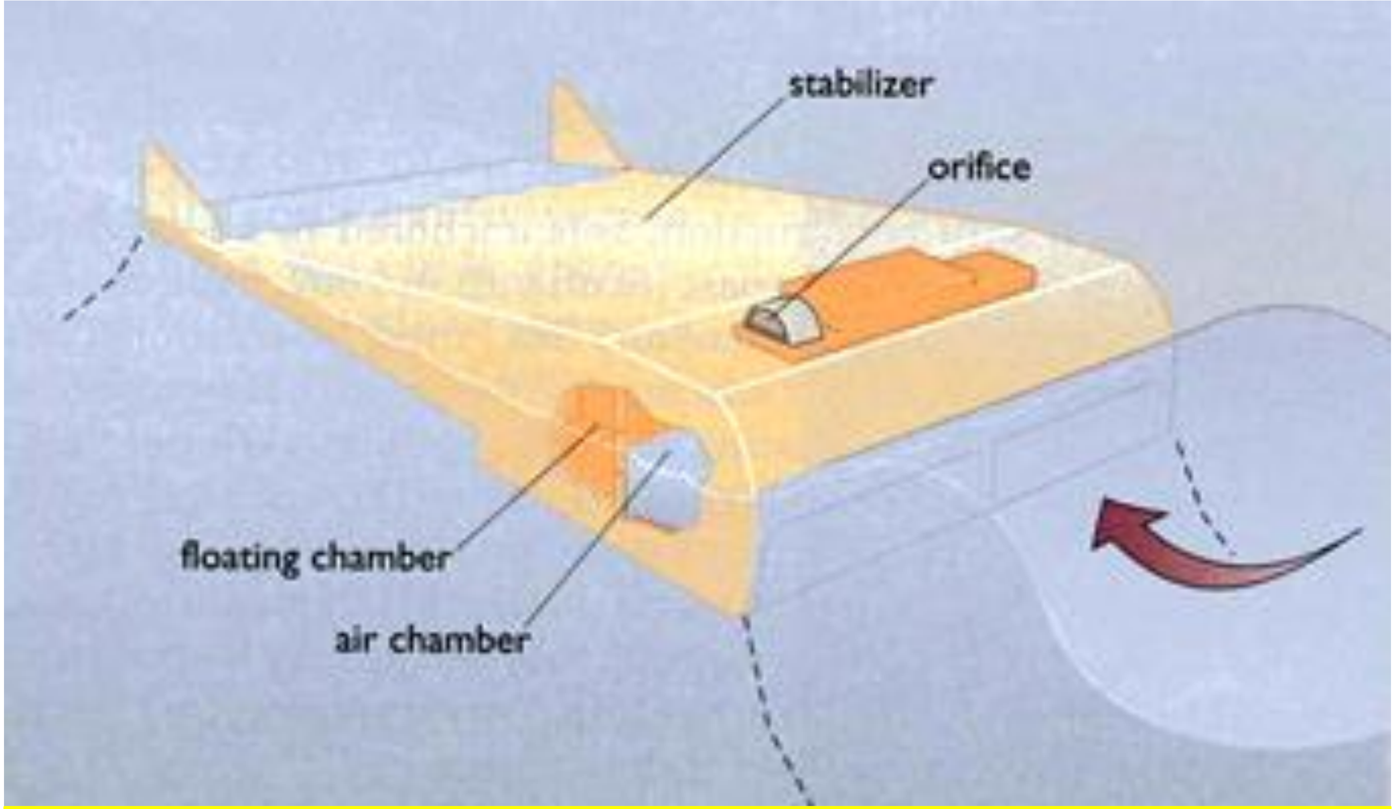
Oscillating Water Column (OWC)



"Mighty Whale" Design – Japan

8.5 Wave Energy Technologies – Terminators

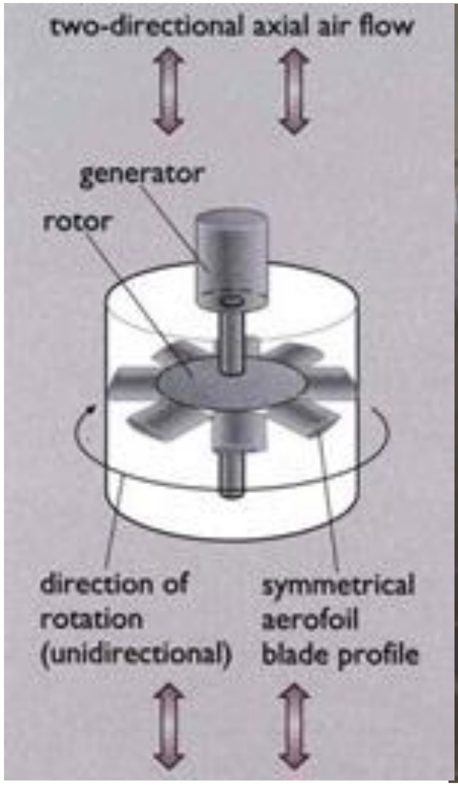
Oscillating Water Column (OWC)



The Whale floating wave energy converter

8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)



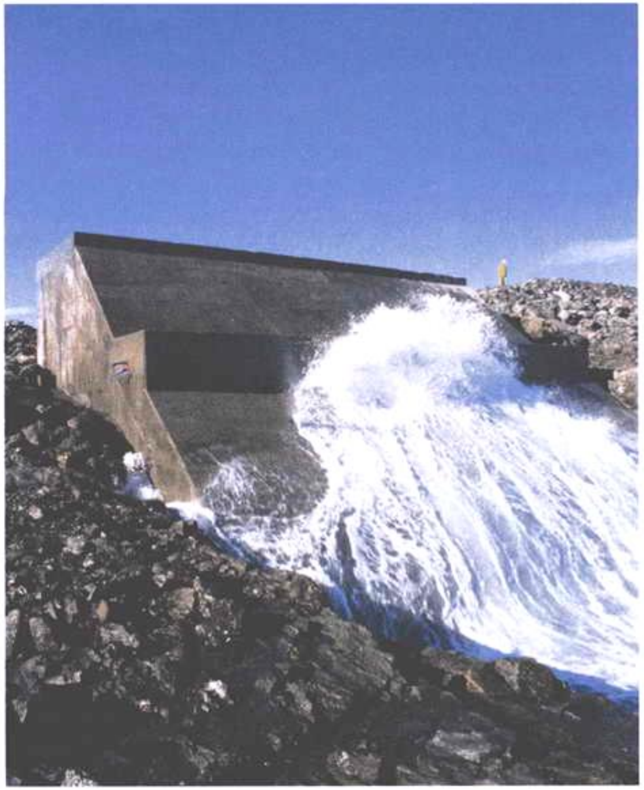
The Wells turbine in Mighty Whale

8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)

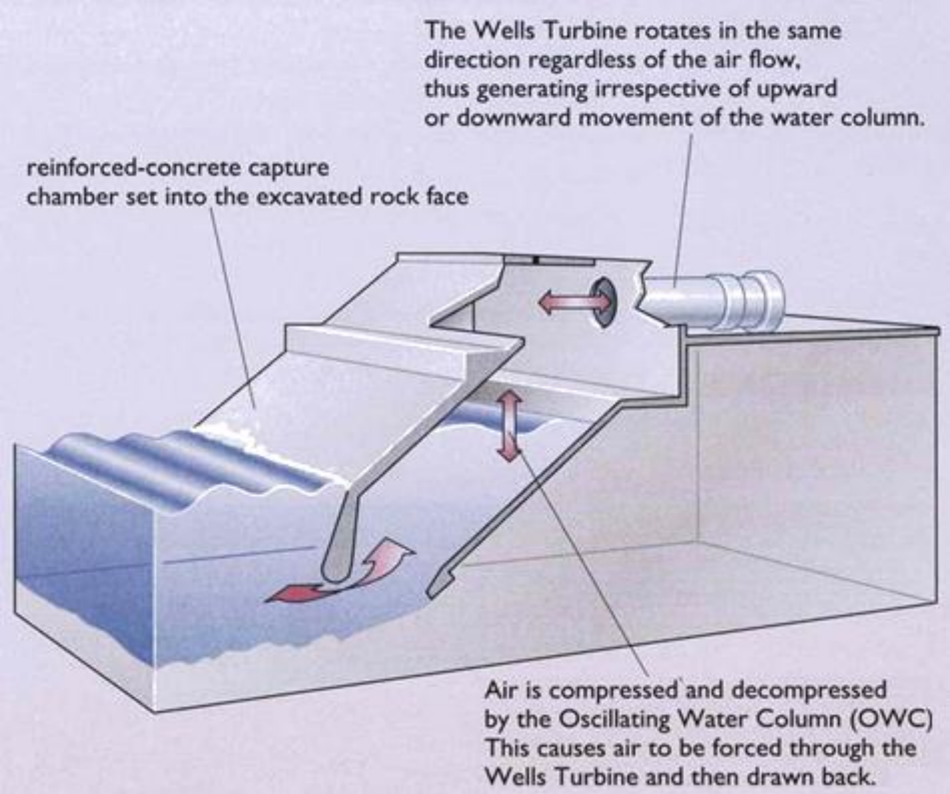
LIMPET Oscillating Water Column

- ☐ Completed 2000
- ☐ Scottish Isles
- ☐ Two counter-rotating Wells turbines
- ☐ Two generators
- ☐ 500 kW max power



8.5 Wave Energy Technologies – Terminators

Oscillating Water Column (OWC)



Outline of LIMPET device in Islay

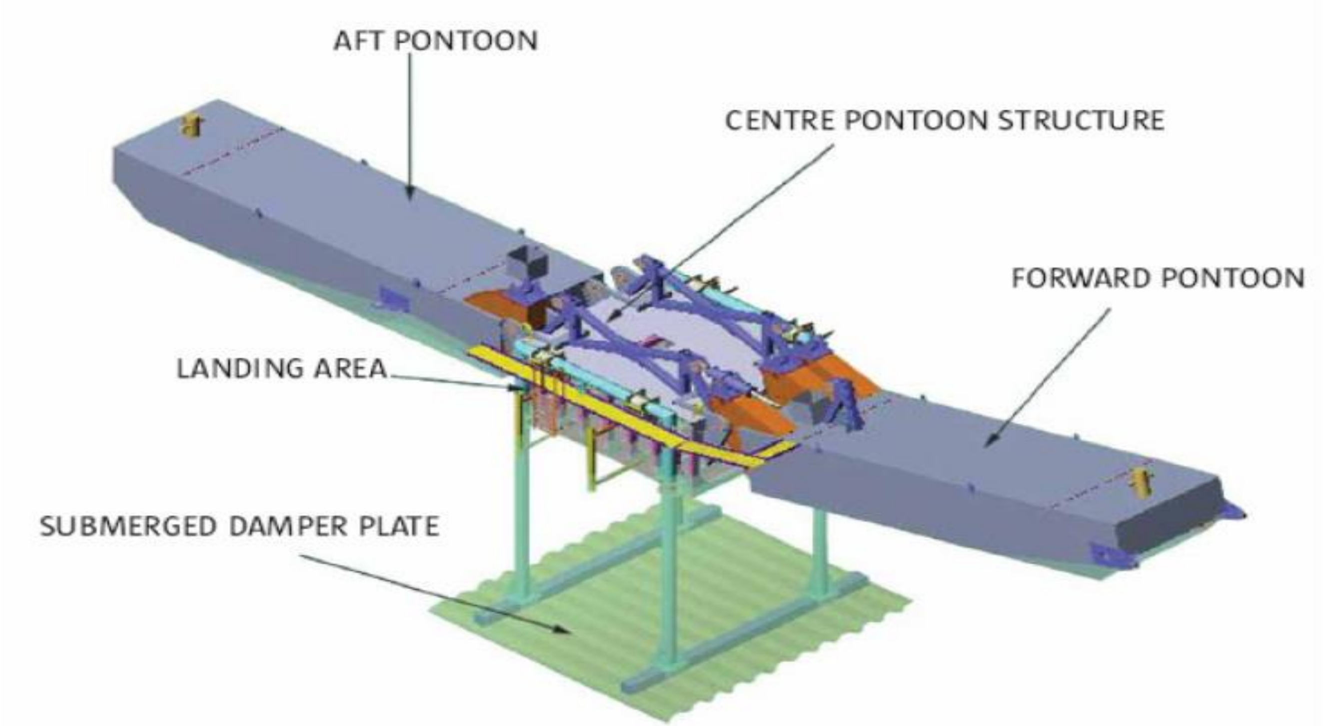
8.5 Wave Energy Technologies – Attenuators

Attenuators are long multi-segment floating structures oriented parallel to the direction of wave travel. The differing heights of waves along the length of the device causes flexing where the segments connect. This flexing is connected to hydraulic pumps or other converters and capture the power of the wave .

Attenuators, McCabe Wave Pump

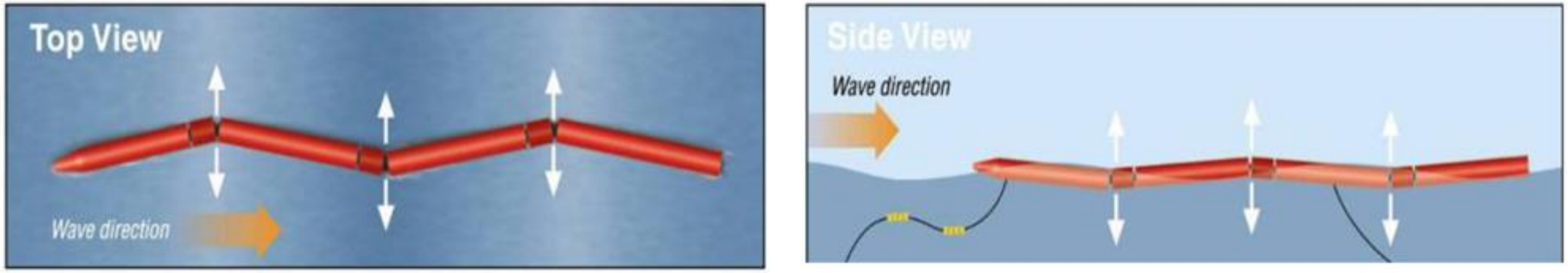
- ☐ The McCabe wave pump has three pontoons linearly hinged and pointed parallel to the wave direction.
- ☐ The center pontoon is attached to a submerged damper plate which causes it to remain still relative to fore and aft pontoons.
- ☐ Hydraulic pumps attached between the center and end pontoons are activated as the waves force the end pontoons up and down.
- ☐ The pressurized hydraulic fluid can be used to drive a motor generator.
- ☐ A 40 meter prototype was tested off the coast of Ireland in 1996 and commercial devices offered.

8.5 Wave Energy Technologies – Attenuators



McCabe Wave Pump

8.5 Wave Energy Technologies – Attenuators, Pelamis Wave Pump

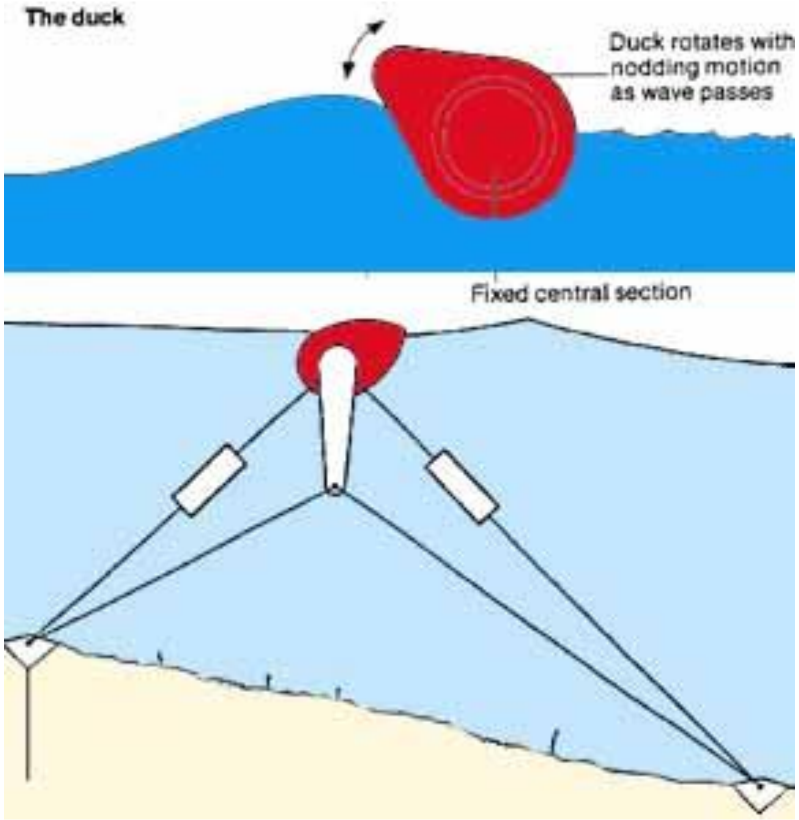


- Pelamis has four 30 m long by 3.5 m diameter floating cylindrical pontoons connected by three hinged joints.
- Flexing at the hinged joints due to wave action drives hydraulic pumps.
- A full scale four segment prototype rated 750 kW was tested for 1000 hours in 2004 and three such machines is being sited about 5 km off the coast of northern Portugal

8.5 Wave Energy Technologies – Attenuators

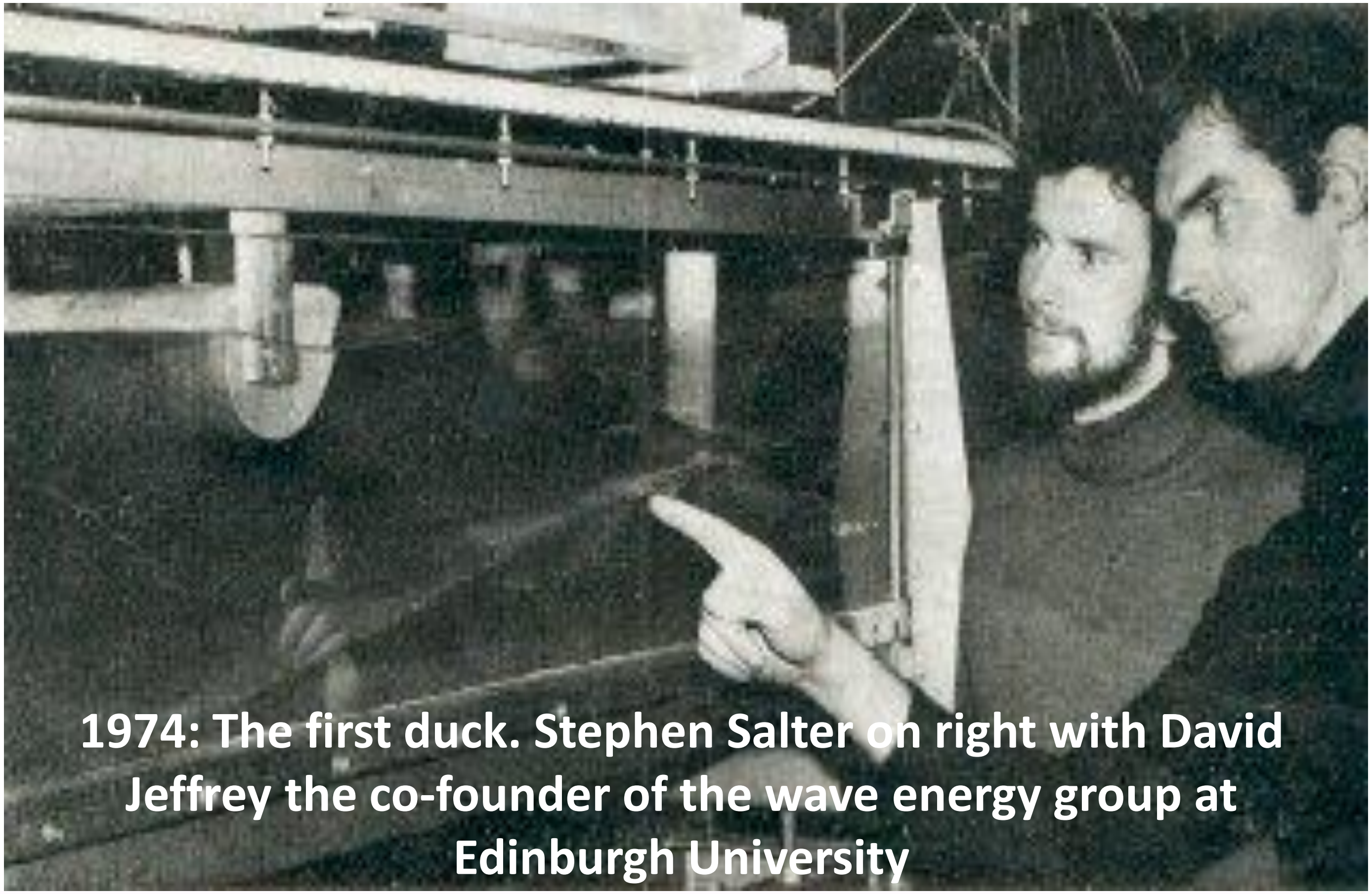
Oscillating Ducks (Salter Duck)

- An array of cam shaped ducks are installed in a linear width-wise array along a line which is perpendicular to the direction of the wave.
- When the forward moving wave front strikes the face of the ducks, (each 25 m long) the ducks start to oscillate.
- The oscillating ducks assembled on a cylindrical spine transfers the motion through linkages and gears to the generator rotor



8.5 Wave Energy Technologies – Attenuators

Oscillating Ducks (Salter Duck)

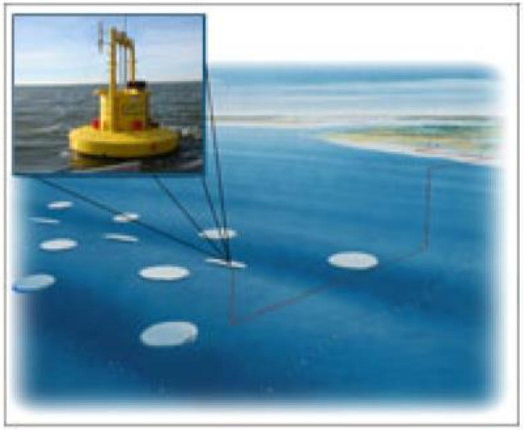


1974: The first duck. Stephen Salter on right with David Jeffrey the co-founder of the wave energy group at Edinburgh University

8.5 Wave Energy Technologies – Point Absorbers

Point absorbers have a small horizontal dimension compared with vertical dimension and utilize the rise and fall of the wave height at a single point for energy conversion.

1) **PowerBuoy** construction involves a floating structure with one component relatively immobile and a second component with movement driven by wave motion. The relative motion is used to drive electromechanical or hydraulic energy converters.



- ☐ A PowerBuoy demonstration unit of 40 kW was installed in 2005 for testing offshore from Atlantic City, New Jersey.
- ☐ Testing in Pacific ocean is being conducted with units installed in 2004 and 2005 off the coast of Hawaii.
- ☐ Commercial scale system is planned for operation in 2007 in northern coast of Spain with 1.25 MW rating

8.5 Wave Energy Technologies – Point Absorbers

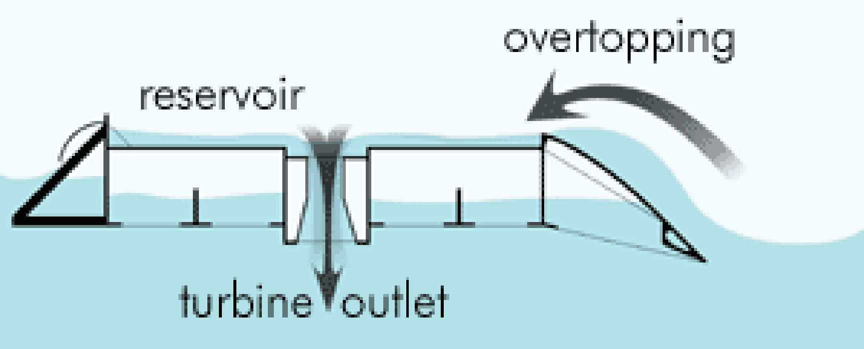
2) AquaBuoy, wave energy pressurizes a fluid which then drive a turbine generator. The vertical movement of the buoy drives a broad, neutrally buoyant disk acting as a water piston contained in a long tube beneath the buoy. The water piston motion in turn elongates and relaxes a hose containing seawater and the change in hose volume acts as a pump to pressurize the seawater.

AquaBuoY point absorber WEC

A 1-MW pilot full scale prototype power plant is located at Makah Bay, Washington 5.9 km offshore in water at 46 m deep

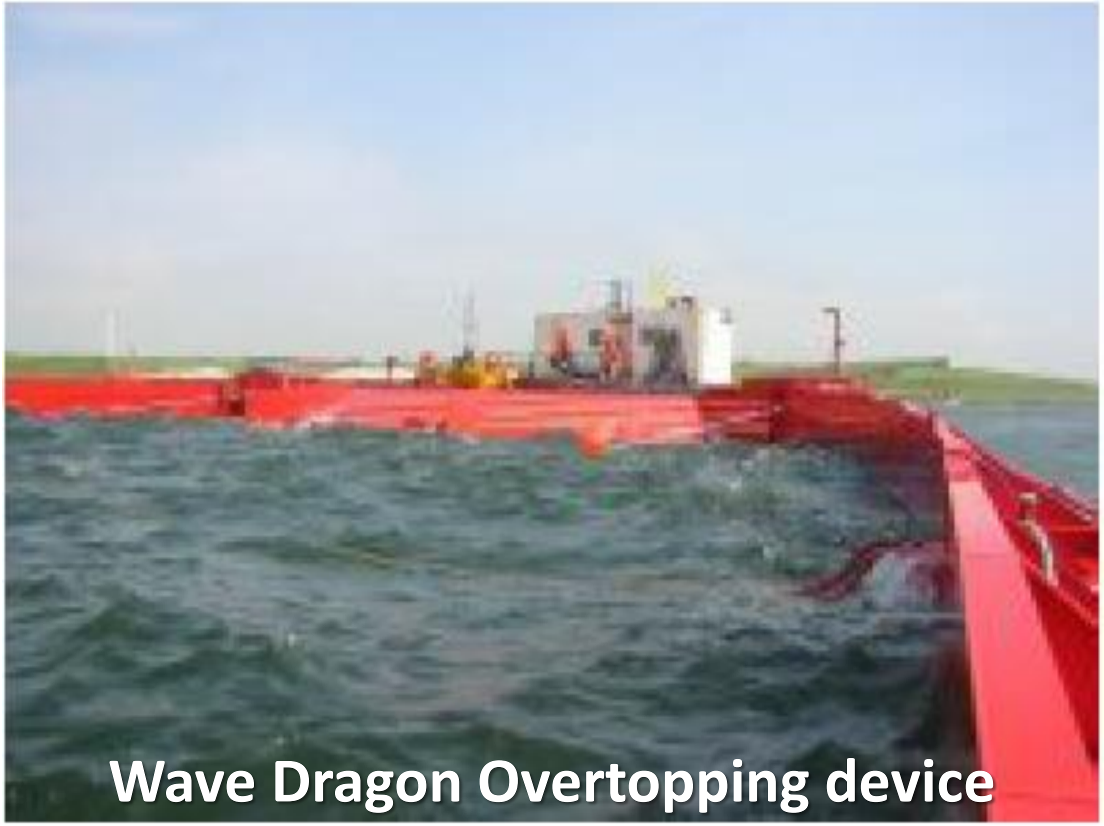
8.5 Wave Energy Technologies – Overtopping, Wave Dragon

- ☐ These devices have reservoirs that are filled by impinging waves to levels above the average surrounding ocean.
- ☐ The released reservoir water is used to drive hydro turbines
- ☐ Prototype demonstration of 7 MW Wave Dragon unit is located off the coast of Wales (2005) and includes wave reflectors that concentrate the waves and rises the effective height of the reservoir.



24kW/m wave = 12 GWh/year
36kW/m wave = 20 GWh/year
48kW/m wave = 35 GWh/year
60kW/m wave = 43 GWh/year
72kW/m wave = 52 GWh/year.

8.5 Wave Energy Technologies – Overtopping, Wave Dragon



Wave Dragon Overtopping device

8.6 Environmental Impact and Economics

- ☐ Visual appearance and noise
- ☐ Some hazard to shipping
- ☐ Reduction in wave height from WEC
- ☐ No problem for migrating fish, marine life
- ☐ Extract small fraction of overall wave energy
    - Little impact on coastlines
- ☐ Little chemical pollution CO_2, SO_2, and NO_x
    - 11g, 0.03g, and 0.05g / kWh respectively

8.7 Advantages of Wave Energy

- ❑ Onshore wave energy systems can be incorporated into harbor walls and coastal protection
  - o Reduce/share system costs
  - o Providing dual use
- ❑ Create calm sea space behind wave energy systems
  - o Development of marine-culture
  - o Other commercial and recreational uses;
- ❑ Long-term operational life time of plant
- ❑ Non-polluting and inexhaustible supply of energy

8.7 Disadvantages of Wave Energy

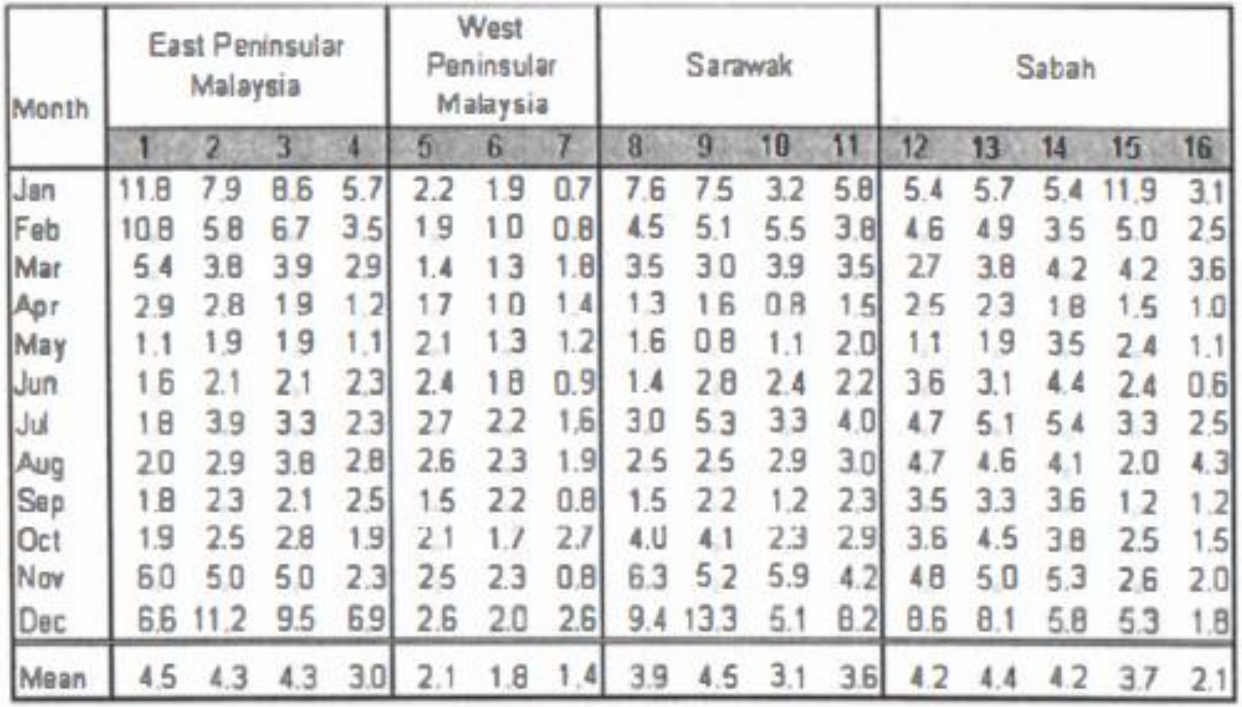
- High capital costs for initial construction
- High maintenance costs
- Wave energy is an intermittent resource
- Requires favorable wave climate.
- Investment of power transmission cables to shore
- Degradation of scenic ocean front views
- Interference with other uses of coastal and offshore areas navigation, fishing, and recreation if not properly sited
- Reduced wave heights may affect beach processes in the littoral zone

8.8 Wave Energy Plants of the Future

- ❑ Potential as significant power supply (1 TW)
- ❑ Intermittence problems mitigated by integration with general energy supply system
- ❑ Many different alternative designs
- ❑ Complimentary to other renewable and conventional energy technologies
- ❑ The offshore wave energy potential is significant.
- ❑ The designs are now towards commercial prototype testing.
- ❑ The environmental impact is expected to be small.
- ❑ Careful monitoring and assessment on environmental impact is also required.

8.9 Wave Energy in Malaysia

- ☐ Sabah and Sarawak is higher , 3.0 - 5.0 kW/m in July – October
- ☐ Peninsular Malaysia is 0.5 - 2.0 kW/m throughout the year



Month	East Peninsular Malaysia				West Peninsular Malaysia			Sarawak				Sabah				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Jan	11.8	7.9	8.6	5.7	2.2	1.9	0.7	7.6	7.5	3.2	5.8	5.4	5.7	5.4	11.9	3.1
Feb	10.8	5.8	6.7	3.5	1.9	1.0	0.8	4.5	5.1	5.5	3.8	4.6	4.9	3.5	5.0	2.5
Mar	5.4	3.8	3.9	2.9	1.4	1.3	1.8	3.5	3.0	3.9	3.5	2.7	3.8	4.2	4.2	3.6
Apr	2.9	2.8	1.9	1.2	1.7	1.0	1.4	1.3	1.6	0.8	1.5	2.5	2.3	1.8	1.5	1.0
May	1.1	1.9	1.9	1.1	2.1	1.3	1.2	1.6	0.8	1.1	2.0	1.1	1.9	3.5	2.4	1.1
Jun	1.6	2.1	2.1	2.3	2.4	1.8	0.9	1.4	2.8	2.4	2.2	3.6	3.1	4.4	2.4	0.6
Jul	1.8	3.9	3.3	2.3	2.7	2.2	1.6	3.0	5.3	3.3	4.0	4.7	5.1	5.4	3.3	2.5
Aug	2.0	2.9	3.8	2.8	2.6	2.3	1.9	2.5	2.5	2.9	3.0	4.7	4.6	4.1	2.0	4.3
Sep	1.8	2.3	2.1	2.5	1.5	2.2	0.8	1.5	2.2	1.2	2.3	3.5	3.3	3.6	1.2	1.2
Oct	1.9	2.5	2.8	1.9	2.1	1.7	2.7	4.0	4.1	2.3	2.9	3.6	4.5	3.8	2.5	1.5
Nov	6.0	5.0	5.0	2.3	2.5	2.3	0.8	6.3	5.2	5.9	4.2	4.8	5.0	5.3	2.6	2.0
Dec	6.6	11.2	9.5	6.9	2.6	2.0	2.6	9.4	13.3	5.1	8.2	8.6	8.1	5.8	5.3	1.8
Mean	4.5	4.3	4.3	3.0	2.1	1.8	1.4	3.9	4.5	3.1	3.6	4.2	4.4	4.2	3.7	2.1

Average Wave Power in Malaysia (kW/m)

Problem 8.1: Wavelength, velocity and area

A progressive sea wave has a wave width of 100 m with a period of 5 seconds. Calculate the wavelength, the wave velocity and the wave area.

Solution

$$\text{Wave Lenght } \lambda = 1.56T^2 = 1.56 \times 5^2 = 39 \text{ m}$$

$$\text{Wave velocity } C = \frac{\lambda}{T} = \frac{39}{5} = 7.8 \text{ m/s}$$

$$\text{Wave area } A = \text{wave lenght} \times \text{wave breadth}$$

$$= \lambda \times B = 39 \times 100 = 3900 \text{ m}^2$$

Problem 8.2: Power density of wave

Ocean waves on an Indian coast had an amplitude of 1 m with a period of 5 s measured at the surface water 100 rn deep. Calculate the wavelength, the wave velocity, the energy density and the power density of the wave. Take water density as 1000 kg/m^3.

Solution

Wavelength, $\lambda = 1.567T^2 = 1.56 \times 5^2 = 39 \text{ m}$

Wave velocity $C = \frac{\lambda}{T} = \frac{39}{5} = 7.8 \text{ m/s}$

Wave frequency, $f = \frac{1}{5}\, s^{-1}$

Energy density $\frac{E}{A} = \frac{1}{2} \times 9.81 \times 1000 \times 1^2 = 4905 \text{ J/m}$

Power density $= \frac{P}{A} = \left(\frac{E}{A}\right) f = 4905 \times \frac{1}{5} = 981 \text{ W/m}^2$

References

[1] BITS, Pilani Dubai on 20130605, student papers 5 Jun 2013

[2] http://ocsenergy.anl.gov/documents/docs/OCS_EIS_WhitePaper_Wave.pdf, Internet 01052010

[3] http://www.slideshare.net/erletshaqe1/oceanicenergy, Internet 28102015

[4] http://www.beachapedia.org/Alternative_Ocean_Energy, Internet 12052011

[5] http://www.authorstream.com/Presentation/abcraja1392502oceanenergytechnologies/ Internet 05042014

[6] http://www.moes.gov.in/final.pdf, Internet 07042014

[7] Morehead State University on 20090720, student papers 20072009

[8] http://www.educationscotland.gov.uk/weatherandclimatechange/energy/renewable/waveandtidal.asp, Internet 28042015

[9] http://www.academypublish.org/papers/fullpdf/2v1n2.pdf, Internet 28072015

[10] M. Ravindran. "Environmental friendly energy options for India", International Journal of Environmental Studies, 12/2007

[11] CSU, Long Beach 20050711, student papers 11072005

[12] http://www.mywindpowersystem.com/2009/09/oceanwaveenergyalternativeenergypart7/ Internet 19122011

[13] http://www.coursehero.com/file/234443/FundamentalsofPhysicsHalliday/ Internet 03042015

[14] Liu, Yajun, Hongda Shi, Zhen Liu, and Zhe Ma. "Experiment Study on a New Designed OWC Caisson Breakwater", 2011 AsiaPacific Power and Energy Engineering Conference, 2011.