COASTAL WAVE ENERGY UTILIZATION COUPLED WITH COASTAL PROTECTION

Paimpillil S. Joseph*, Baba.M.

* Center for Earth Research and Environment Management, Cochin 17, India.

Center for Earth Science Studies, Trivandrum, Kerala, India.

Overview

- Introduction
- Results
- Conculsions
- Recommendations
- Acknowledgement

Introduction

- According to estimates, the sea waves contain as much energy as the world is consuming today.
- Waves can provide huge amount of electricity without cooling towers and pollution.
- Also, there is no fear of the fuel running out as the waves go on forever.

The wave power potential depends upon harnessing the long wavelengths, long period and deep-water ocean waves.

The wave power devices absorb the mechanical energy of waves and convert it into electricity.

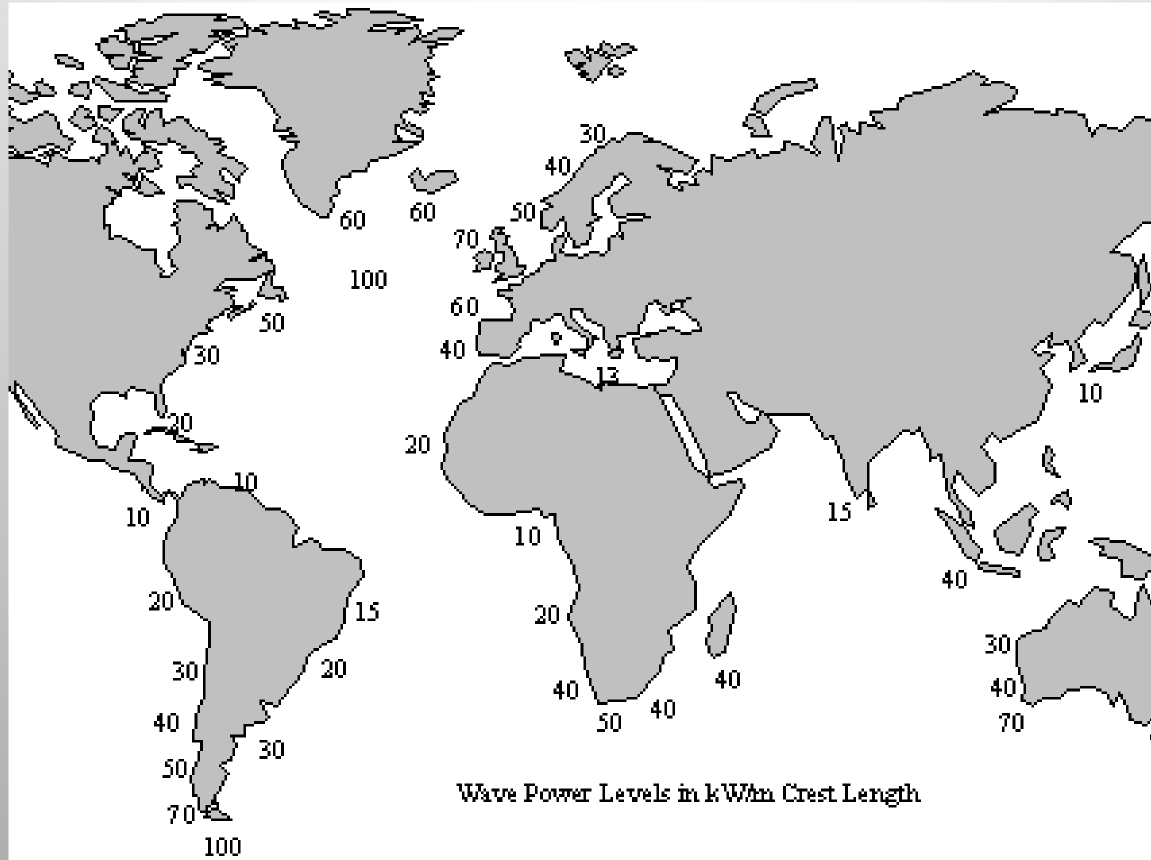
- Works on wave energy began in the 1970s
  - as a response to the emerging oil crises.
- There were several government sponsored programs throughout the world,
  - particularly in Japan, Norway and the UK.
- These programs advanced the technology considerably and their achievements were impressive.
- Nevertheless, the failure of these programs to deliver economic supplies of electricity from wave energy
  - left the technology with a credibility problem that has been hard to overcome.

- Since the mid-1990s, there has been a resurgence of interest in wave energy
  - led mainly by small companies.
- Their Endeavour’s progress the technology
  - so that there are now a number of different devices that have been built or that are under construction at this moment around the world.
- Hence, the next few years will be very interesting for wave energy
  - as these full-scale prototypes provide the in service experience required
  - for developing a more mature technology.

- In India’s perspective, there is tremendous scope for the sea wave energy.
- There are about 336 Indian islands in Bay of Bengal and Arabian Sea.
- The electricity generated from sea wave power stations there, can very well fulfill the requirement of that area.
- Also, India has a long coastline of about 6,000 km.
- The coastlines are hit by sea waves round the clock and can be exploited for electricity generation.
- The Indian wave energy program started in 1983 at the Institute of Technology (IIT) under the sponsorship of the Department of Ocean Development, Government of India.

World wave energy potential

- Considerable amount of energy is present in the ocean waves pounding against a coastal line.
  - However, it is not from the breaking waves that the energy can best be extracted .
- The water's surface acts like a great conveyor belt delivering power from great distances.
- The wave power can be stated to be: **$P = 0.55\ H^2_s\ T_z$ kW/m** length of wave crest, where **T_z** is the zero crossing periods.



WAVE POWER LEVELS IN KW/M CREST LENGTH

Wave conditions in north Indican Ocean

- The wave conditions in Arabian sea and in Bay of Bengal are mainly controlled by south west monsoon winds and by tropical cyclones.
- The recent wave measurements in the coastal waters of India had shown waves up to 6m in significant height
- Two sites suitable for wave energy extraction are the Orissa coast of Bay of Bengal and the Andaman seas.

Area	Month	Average	Maximum	Minimum
Bay of Bengal – Andaman Sea	April	1.24	1.59	0.86
	May	2.10	3.46	1.36
	June	3.09	4.90	1.25
	July	2.29	3.30	1.25
	Aug	2.72	4.29	1.54
	Sep	2.37	4.41	1.54
	Oct	1.79	3.69	1.04
	Nov	1.25	1.63	0.75
Bay of Bengal Orissa coastal regions	May	2.49	3.61	1.39
	June	3.41	5.99	1.39
	July	2.25	3.59	1.50
	Aug	2.78	5.83	1.46
	Sep	2.45	5.78	1.26
	Oct	1.67	2.85	1.55
	Nov	0.92	1.38	0.64

Monthly significant wave heights (m) at 2 regions in Bay of Bengal

Wave power potential for Indian coastline

- Primary estimates indicate that the annual wave energy potential along the Indian coast is between 5 MW to 15 MW per meter.
- Hence theoretical potential for a coast line of nearly 6000 Km works out to 60000 MW approximately.
  - However, the realistic and economical potential is likely to be considerably less and 47 kW/m is available off Bombay during Southwest monsoon period.
- Based on the wave statistics for the southern tip of India, a mean monthly wave power of 4 - 25 kW/m is estimated.
- The average wave potential along the Indian coast is around 5-10 kW/m.
- India has a coastline of approximately 6500 km. Even 10% utilization would mean a resource of 3750 –7500 MW.

Wave climate estimation

- A number of wave models are currently in use to predict / hindcast the ocean wave conditions.
- The wave models are beneficial: but they are subject to considerable error as the model domain approaches the shallow coastal zones.
- A lack of real-time or historical wave data in coastal ocean regions makes all classes of numeric wave models subject to considerable error in the coastal region.
- The models are still necessary but they are not sufficient by themselves to provide accurate information about littoral wave environment.

Single parameterized wave prediction /Hindcast model

- A simple, fast and accurate model
  - tested for the wave conditions in different oceanic regions
  - This prediction model depends on **2/3 Power law (Toba, 1972)**
  - Capable of providing significant properties and spectrum of wave field

2/3 Power law

- Toba (1972) proposed a power law type relation
  - between the significant wave height **Hs** and significant wave period **Ts**
- Three-Second Power law is states as:
- **H*s = BTs*3/2**,
  - where H*s defined as gHs/u*2,
  - T*s as gTs/u*,
  - U* = frictional velocity, B = 0.062

Single parameter growth equation

- With the usage of the similarity based power law and the spectral from
  - Toba (1978) proposed a single parameter growth equation for the wind wave part of the ocean waves.
- **G = G0 [1-erf(bσ σp*-1)]**
  - **G** defined as that part of the momentum retained in the form of wave momentum to total momentum transferred to the sea
    - **G0** represents maximum value of **G** when waves are in the underdeveloped stage and it was given a value equal to **0.062**.
    - The **σp** is the non dimensional angular frequency and **bσ =0.12**.
- This single parameter equation forms the basis of the prediction of the wind wave's part of the ocean wave spectrum.

Hybrid wave prediction / hindcast model

- The only requirement for running this Hybrid wave prediction / hindcast model is friction velocities at regular intervals on a grid system covering the required near-shore region.
  - The friction velocity field over oceanic region can be estimated from the pressure fields and the wave predictions / hindcasts using such wind fields were found to be sufficiently accurate
- Kawai et al. (1979) and Joseph et al. (1981) used the single parameter growth equation in wave hindcasting,
  - and its applicability in Open Ocean was substantiated

- .The prediction accuracy depends on spatial and temporal distribution of wind data.
- It seems to be possible to use climate models in preparing the past wind fields and can be utilized in the construction of the paleo- wave climate of any oceanic region using the Hydrid ocean wave hindcast model.
- The wave climate studies using the measured /hindcasted deep and shallow water waves in the south west Arabian sea had shown that swells with mean height of 1.5 m dominate the wave field except during the monsoon season (June - September),with wind waves reaching up to 6.5m in monsoon months.

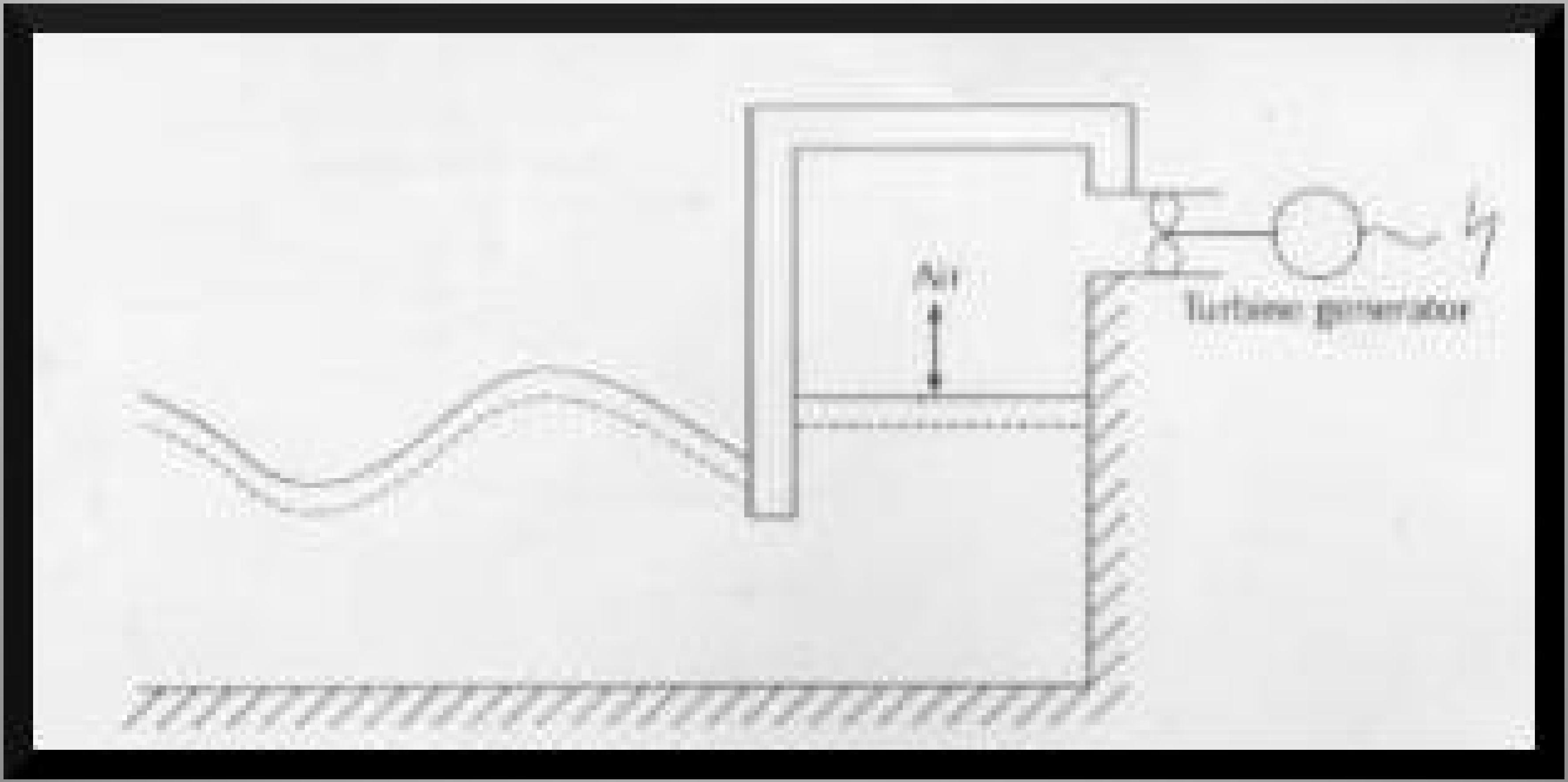
Principle of the wave energy converter

- A few hundred patents have been registered worldwide on different types of wave energy converters.
- However, it is widely recognized that the only device that can be built to even a moderate degree of satisfaction, using presently available construction techniques, is a shoreline OWC.

OWC

- An OWC consists of
  - a partially submerged, hollow structure,
    - which is open to the sea below the water line.
- This structure encloses a column of air on top of a column of water.
- The incident waves cause the water column to rise and fall, which alternately compresses and depressurizes the air column.
- If this trapped air is allowed to flow to and from the atmosphere via a turbine,
- Energy can be extracted from the system and used to generate electricity.

The Oscillator water Column



Indian Wave Power Plant at Vizhinjam

Power plant output

- The power plant delivers 75 kW during April - November
- 25 kW from December - March.
- During June - September, it has peaks of 150 kW.
- The monsoon month's average power production was 120 kW.
- Nine month average value of the incident wave power is 10 kW/m and peak monsoon average is 20 kW/m.

Cost of power plant

- The cost of construction of the power plant was 99 lakhs Indian rupees
- it produces 4.45 lakhs units of electricity per year.
- The unit cost stands 0.73 rupees, while the power from hydroelectric generators cost around 1.5 rupee per unit.
- As the cost of production is comparably less and the harnessing of wave energy is more economical than the wind energy,
- small wave generation units are suitable for regions of persistent swell activity such as semi enclosed seas where wind waves development is limited by fetch and wind velocity.

Renewable Energy Options

- India's main achievements in the renewable energy sector have been in developing
- wind power,
- solar energy -- both thermal and photovoltaic,
- biomass
- and small hydro technologies.

Wind Power	7,844.57 MW
Solar Power	2.12 MW
Small Hydro (up to 25 MW)	2,045.61 MW
Waste to Energy	55.20 MW
Bio Power (Agro residues)	605.80 MW

Grid-interactive Renewable Power

Wind Power

- The installed wind power generation in India is about 5000 MW.
- A single machine generation potential is upto2.1 MW with an average capacity factor 14%.
- The capital cost for wind energy generation is Rs4-5crores/MW, Rs2-3/kWh (cost effective if site CF >20%).

Tidal energy

- The most attractive locations for tidal energy are the Gulf of Cambay and the Gulf of Kachch on the west coast
  - where the maximum tidal range is 11 m and 8 m with average tidal range of 6.77 m and 5.23 m respectively.
- The Ganges Delta in the Sunderbans in West Bengal also has good locations for small scale tidal power development.
- The maximum tidal range in Sunderbans is approximately 5 m with an average tidal range of 2.97 m.

Tidal energy

- The identified economic tidal power potential in India is of the order of
- 8000-9000 MW with about 7000 MW in the Gulf of Cambay about 1200 MW in the Gulf of Kachch
- and less than 100 MW in Sundarbans.
- The Kachch Tidal Power Project with an installed capacity of about 900 MW is estimated to cost about Rs. 1460/- crore generating electricity at about 90 paise per unit.

Ocean Thermal Energy Conversion

- In India activities in this area are coordinated by the OTEC Cell at Indian Institute of Technology, Madras.
- A feasibility study of setting up a 5 to 8 MW pilot R & D OTEC plant off the main Anandman Islands is ready
- and a proposal for a feasibility study for installation of a 100 MW OTEC plant off Madras is under consideration.

Advantages of the breakwater-OWC

- There has been considerable debate about the actual costs of generating electricity from waves and the likely future cost.
- It is undisputed that the generating costs of prototypes are high
  - because all the high fixed costs associated with a wave energy scheme (permits, surveys, grid connection) are defrayed against the output of a single device.
- In addition, prototype devices are, by definition, immature and hence they will perform less well than follow-on schemes.

Advantages of the breakwater-OWC

- From the viewpoint of the electricity producer, the breakwater-OWC has the advantage that the installation costs are reduced by sharing them with the harbour authorities (or similar) that want to shelter an area or a structure from the waves.
- From the viewpoint of someone who wants to protect something against wave attack, the breakwater-OWC has the advantage that the installation costs are reduced by sharing them with an electricity producer.
- From the coastal engineering point of view the system has two large advantages over "normal" breakwaters: (1) the wave height in front of the device is reduced, as the wave energy is absorbed and not reflected; (2) the wave forces do not (only) act against the structure, they act to move the turbine, so the loads are reduced.

Environmental impact of wave energy schemes

- The environmental impact of wave energy schemes is '…likely to be low,
  - provided developers show sensitivity with appropriate site selection and planning authorities control deployment in sensitive locations'
- Operational experience of the limited number of devices employed to date confirms this .
- the largest environmental impact having been noise from the Wells turbines employed in some OWCs,
  - which was reduced by adding acoustic baffles.

Conclusion

- The wave power offers many advantages over the renewable sources like wind and solar.
- Both the wind and solar forms require hundreds of square acres of useful open land, for their installation.
- Wind farms are also the source of noise pollution.
- Moreover, the working of solar forms depends on the consistency of the weather, thus rendering it viable only for small areas on the globe.
- Now, what is needed, are the government utilities and the industry's capital that will turn the wave power devices into major energy provider.

Conclusion

- Wave energy is a renewable energy, like solar and wind energy
  - The idea is that energy can be produced from these abundant natural resources and help reduce the consumption of fossil fuels and pollution.
- There is also an educational purpose.
- A working display of the device helps students and the public to understand
  - how the device works
  - to learn more about non-solar energy
  - To raise awareness about wave energy among school students.

  - The wave energy plant at Vizhinjam has shown that a random and diffuse form of energy can be concentrated to convert it into electrical energy that can be exported via the electrical grid.

Recommendations for wave energy exploitation

- At present, more than 80% cost of the wave energy plant is due to civil construction (concrete caissons).
- Considerable cost savings can be obtained using the concept of multi-functional breakwaters wherein a power module forms an incremental addition to a caisson breakwater.
- it is uneconomical to construct a bottom standing caisson structure in deeper water where energy potential is high.
- constructing floating devices reduces the forces on the structure without significant loss in absorbed power.

Thank You

Wave energy

- Considerable amount of energy is present in the ocean waves pounding against a breakwater.
  - However, it is not from the breaking waves that the energy can best be extracted
- The water's surface acts like a great conveyor belt
  - delivering power from great distances.

  - The wave power can be stated to be: **P = 0.55 H2s Tz kW/m** length of wave crest,
  - where **Tz** is the zero crossing period .

Energy of the wind waves

- Toba proposed a simple spectral form
  - for the wind waves for the high frequency side.
- The relation between total energy of the wind wave **E** and the peak frequency **fp** as:
- **E* = Bf fp*-3,**
  - **Bf = 2.1 x 10-4**
  - Where **E*** defined as **g2 E /u*4** ,
  - **fp*** as **u*fp /g**
  - where **fp = (1.05 Ts)-1 , E = Hs2/16.**

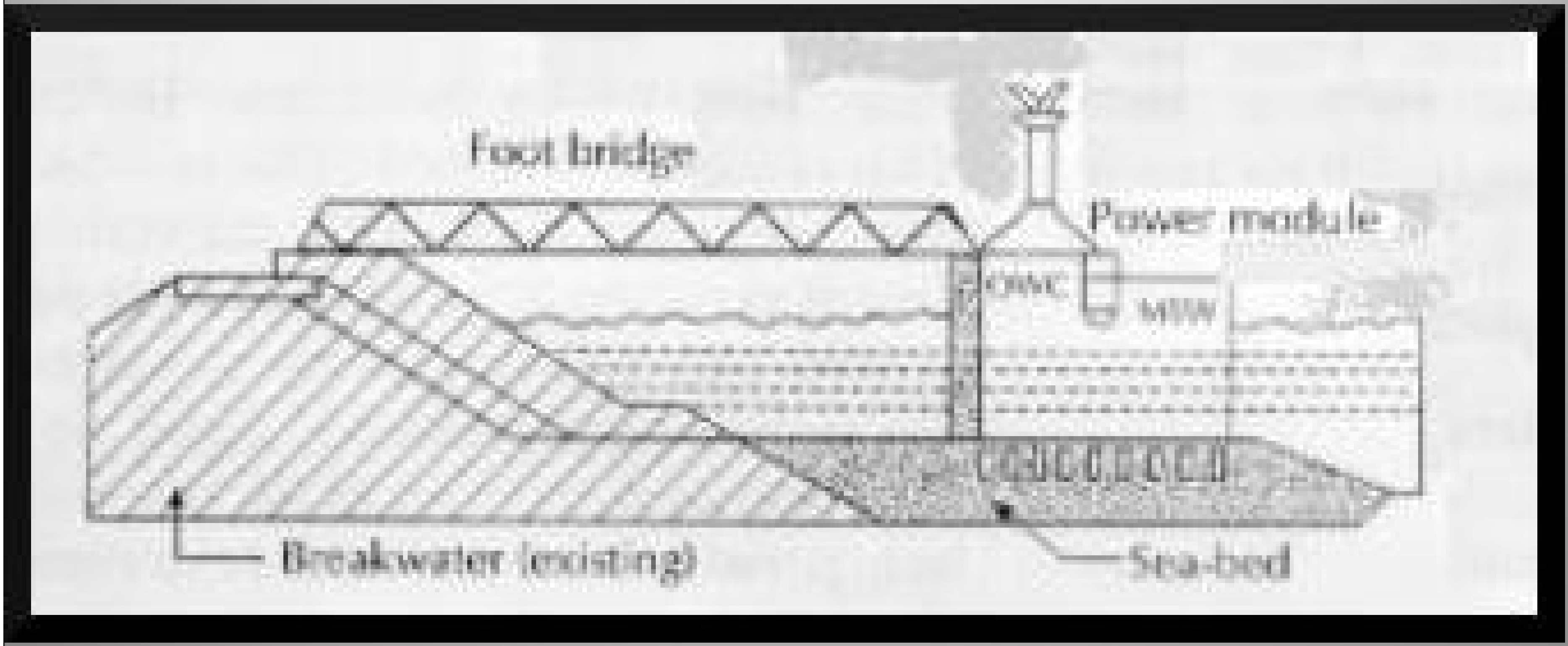
Swell fields

- Swell field are treated by empirical relationship by Bretschneider (1968)
  - gave only the gross nature of swells
- A spectral treatment for swell was incorporated with the single parameterized wind wave’s part of wave prediction in Joseph (1981)
  - Hybrid ocean wave prediction model was tested in the cyclone weather conditions in Atlantic ocean and in the land locked regions of the Japan sea
    - with very accurate predictions.

Wave power potential for Indian coastline

- The estimated wave power potential for Indian coastline is of the order of 40000MW
- 47 kW/m is available off Bombay during Southwest monsoon period
- Based on the wave statistics for the southern tip of India, a mean monthly wave power of 4 - 25 kW/m is estimated.
- The average wave potential along the Indian coast is around 5-10 kW/m.
- India has a coastline of approximately 7500 km. Even 10% utilization would mean a resource of 3750 –7500 MW.

Cross Section of wave energy device and breakwater



Description of the Indian wave energy plant

- Based on studies (Raju, Ravindran 1987, Raju, Ravindran 1989) on three types of devices, namely, double float system, single float vertical system, and the OWC principle,
- it was concluded that the OWC showed the maximum promise for India.
  - The OWC wave energy device is a resonating device which can be tuned to any predominant frequency of the wave by altering the dimensions of the device.
- The fishing harbour at Kovalam is the site of a unique demonstrations plant that converts wave energy into electrical energy that can be exported via the local electricity grid.

Design and installation of caisson

- The wave forces were estimated by treating the caisson as a vertical wall obstruction for the waves (Neelamani et.al (1992).
  - The highest probably non-breaking wave force was 1200 tonnes.
- The highest probable breaking wave was estimated to be 7 m.
- The force intensity has a peak of 100 tonnes / m2.
- The OWC with the harbour was built as a cellular concrete caisson.
  - The design is of the gravity foundation type.
- The concrete structure weighs 3000 tonnes and is further ballasted in its hollow chambers using about 3000 tonnes of sand.
  - This concrete ballasted caisson is seated on a prepared rubble bed.
  - The top of the CWC chamber is a double cubic curved shell in concrete 10 x 7.75 m at the bottom, reducing to 2.0 m circle at the top and 3.0 m high to support the power module

Power outputs

- The energy in the waves is converted by the OWC caisson into pneumatic energy
- The power take-off mechanism is the Wells turbine connected to a generator.
- The generator delivers the electrical power to the grid.
- The theoretical maximum conversion efficiency of the caisson (wave to pneumatic) at any given period (frequency) of the incoming wave is determined purely
  - its geometry,
  - the direction of the wave,
  - and an optimum value of the `damping' on the caisson.

- This value of the optimum damping is frequency dependent.
- Thus, the conversion efficiency of the caisson under operating conditions is governed by the load characteristics.
- The maximum average capacity of the caisson is estimated to be in excess of 240 kW under optimum load conditions.
- This estimate is based on the average monsoon input wave condition of 20 kW/m, 10 m caisson opening, and an average capture factor of 1.2 over the frequency range of interest

Typical Power output to grid (Cited from Raju et al, 2004)