Linking of wave energy utilization with coastal protection

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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 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. Now, what are needed: the government utilities and the industry's capital that will turn the wave power devices into major energy provider?

World wave energy potential

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: $P = 0.55\ H^2_s\ T_z$ kW/m length of wave crest, where T_z is the zero crossing periods.

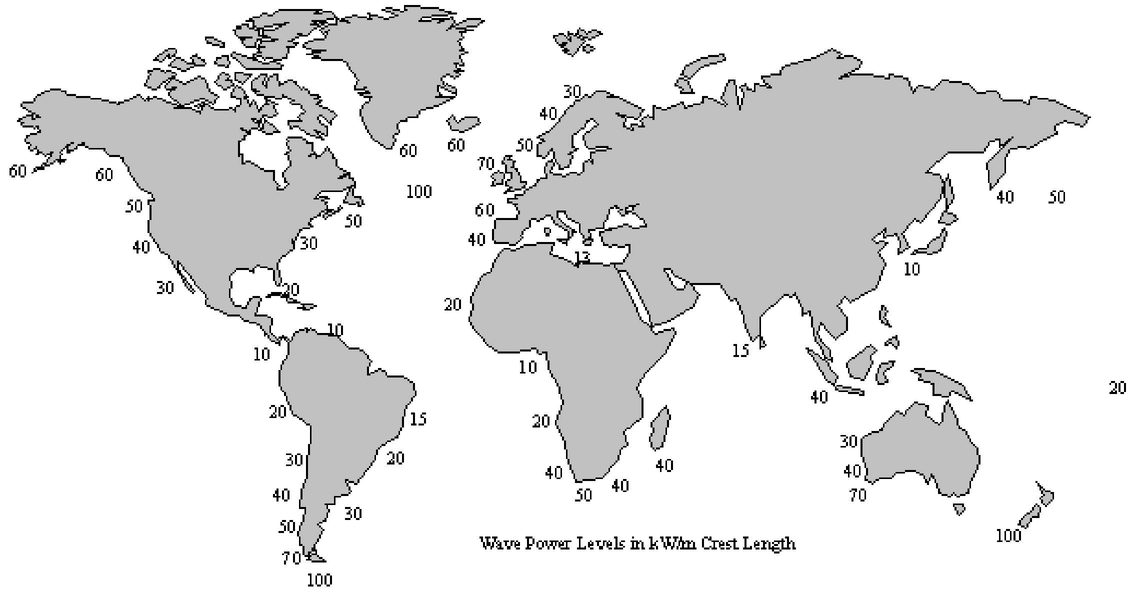


FIG. 1 *WAVE POWER LEVELS IN KW/M CREST LENGTH*

Wave power potential for Indian coastline

In India the research and development activity for exploring wave energy started in 1982. 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.

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. 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.

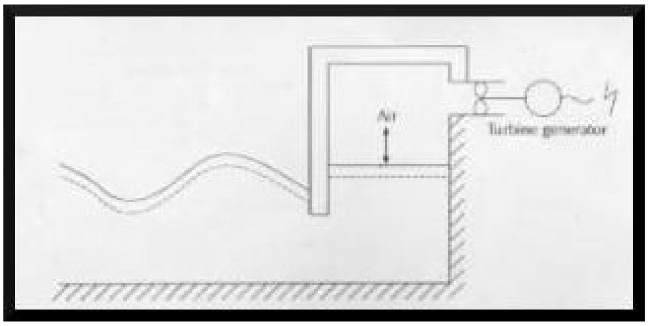


FIG. 2 THE OSCILLATOR WATER COLUMN

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. Kerala is one South Indian state that has not taken up renewable energy in a big way. While neighboring Tamil Nadu has a wind power generation capacity of 3000 MW, Kerala has nothing despite tremendous potential especially in the hilly regions and limited wave energy potential along the southern beaches. 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.

FIG 3. *THE OWC PROTOTYPE DEVELOPED AT THE IIT*

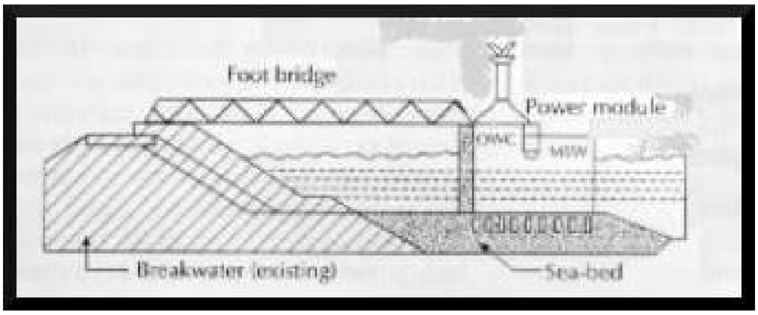


FIG 4. CROSS SECTION OF WAVE ENERGY DEVICE AND BREAKWATER

Wave energy

Waves are generated by the force of the wind blowing over the ocean's surface. The regular breakers seen on most beaches originate at sea and can come from a variety of storms. The water's surface acts like a great conveyor belt, delivering power from great distances.
The average power **P (W/m)** in a regular sine-wave per meter wave front of waves with height **H** and period **T** can be expressed as:

$$P = rg^2H^2T/8p \text{ ,}$$

where **r** is the density of water, **g** the acceleration of gravity.
The wave power can also 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 period.

The estimated wave power potential for Indian coastline is of the order of 40000MW, with 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.

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. 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.

Description of the Indian wave energy plant

A well-known beach in Kerala is at Kovalam. This fishing harbour is the site of a unique demonstrations plant that converts wave energy into electrical energy that can be exported via the local electricity grid. The initial research conducted by the Wave Energy Group, IIT Chennai focused on the choice of the wave energy device (Raju, Ravindran 1987, Raju, Ravindran 1989). Based on studies 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. Consequently, development activities were concentrated on this device alone. The plant works on what is known as the OWC principle. Energy is extracted from the system and used to generate electricity by allowing the trapped air to flow via a turbine.

Design and installation of caisson

The caisson is predominantly subjected to wave forces. The wave forces were estimated by treating the caisson as a vertical wall obstruction for the waves. The highest probably non-breaking wave force was 1200 tones. The highest probable breaking wave was estimated to be 7 m. The force intensity has a peak of 100 tones / 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 tones and is further ballasted in its hollow chambers using about 3000 tons 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. Details about the construction like seabed preparation, towing, and seating can be found in Neelamani et.al (1992).

Power outputs

The plant was first commissioned in October 1991. Figure 5 shows a typical power output to the grid. 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. A part of the electrical power is also dissipated in the resistances externally connected to the rotor of the generator. The theoretical maximum conversion efficiency of the caisson (wave to pneumatic) at any given period (frequency) of the incoming wave is determined purely by its geometry, the direction of the wave, and an optimum value of the `damping' on the caisson. In this case the damping is determined by the turbine and the generator. This value of the optimum damping is frequency dependent.

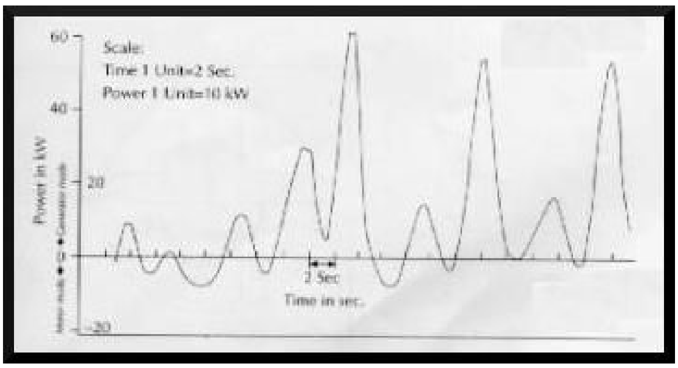


FIG 5. TYPICAL POWER OUTPUT TO GRID (NEELAMANI ET AL, 2004)

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.

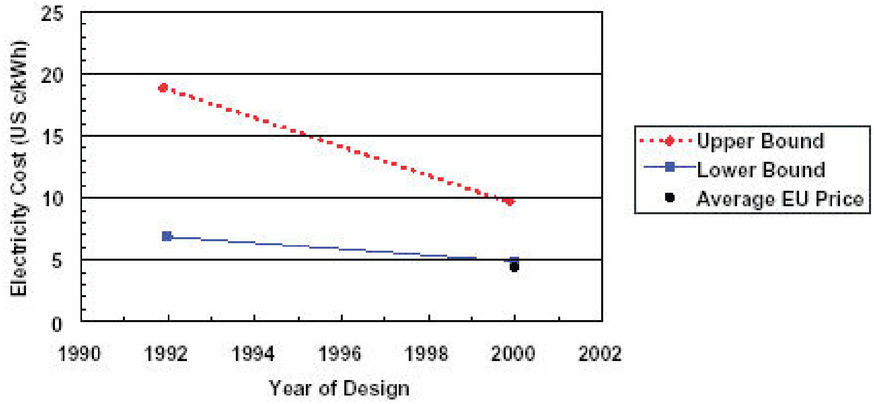
This power plant delivers 75 kW during April - November and 25 kW from December - March. During June - September, it has peaks of 150 kW. The monsoon month's average power production was 120 kW. It is noted here that the nine month average value of the incident wave power is 10 kW/m and peak monsoon average is 20 kW/m. The cost of construction of this power plant was 99 lakhs Indian rupees and 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 as the sea acts as a mechanical collector of wind energy with the smoothing of the spatial and temporal variability in the wind field, such 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.

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.

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.

Likely generating costs of arrays of mature devices located in promising wave energy sites and shown a steady reduction in generating costs over the past decade; so that there are now a few devices with the potential to generate electricity at US 5–10 cents/kWh (at 8% discount rate including grid connection and all annual costs such as O&M and insurance). The costs of generation from prototypes are likely to be 2–3 times this.



[1]FIG 6. *WAVE GENERATING COSTS*

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 use of ocean waves energy is in its infancy today but can lead to clean, affordable and renewable electrical power. Right now, it's probably 15 years behind wind energy, but it has a vast potential. 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 it helps to reduce the consumption of fossil fuels and pollution. The benefit of this wave project is that collector provides invaluable information about the feasibility of applying wave energy in coastal nations. There is also an educational purpose. A working display of the device helps students and the public to understand how the device works and to learn more about non-solar energy that raise awareness about wave energy among school students. 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.

References

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[2] Raju, Ravindran (1989). The initial research conducted by the Wave Energy Group, IIT Chennai Technical report.