Energy from sea waves—the Indian wave energy programme

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Ocean energy is one of the important forms of renewable energy. Wave energy has received considerable attention in the recent past. In India the Department of Ocean Development (DoD), Government of India, has sponsored wave-energy research at the Ocean Engineering Centre of the Indian Institute of Technology, Madras.

Future energy-supply projections suggest that there will be problems in matching supply and demand early in the next century. Furthermore, since the cost of primary energy will almost certainly rise, alternative forms of energy conversion must obviously be investigated and developed as either supplementary or insurance technologies.

Power generation in India today is mainly from hydroelectric and thermal power plants. The present total installed capacity hardly meets the grid demand. Uncertainty of the monsoon and problems of coal transport put a strong limitation on expansion of present generation capacity. But the increase in standard of living and rapid industrial growth necessitate a high rate of growth of power supply. The price of oil continues to be high in India. The present contribution of power generation from nuclear plants is small, and the uncertainty in the protective measures against all environmental hazards of such plants indicates that development of renewable energy sources is important for India.

One important renewable source is ocean energy. Solar radiation, which sustains life on earth, is continuous and inexhaustible. It has been estimated that about 10^{16} W of solar energy reaches the earth. The ocean, which covers nearly 71% of the earth's surface, acts as a natural collector of this energy. Thus the ocean has an enormous potential to supply energy in many different ways. The major advantages of ocean energy are that it is renewable and continuous throughout the year, is pollution-free, and has minimum health hazard. For remote islands, ocean energy will be the most important form of alternative energy since it comes from the immediate vicinity.

Sea waves as source of energy

The incessant motion of the sea surface in the form of wind waves constitutes a source of continuous energy. About 1.5% of the incoming energy from the sun is converted to wind energy. Part of the energy from the winds is transferred to the sea surface, resulting in generation of waves. This energy is carried to coastlines throughout the world, where it is dissipated as the waves break. If this source can be tapped properly and used economically, it can generate a sizeable portion of world energy needs.

Extraction of energy from waves is more efficient than directly from wind, since wave energy is concentrated through interaction of the wind and the free ocean surface. The sea behaves like an immense energy collector whereby the wind energy, transferred to the large sea surface, is stored as mechanical energy in waves. The inertia of waves provides this short-time storage and partly smoothens the high variability of the wind over time and space.

Though the potential along the 6000 km of the Indian coast is quite substantial, estimated to be around 40,000 MW, the energy is less intensive compared to that in more northern and southern latitudes.

Ocean waves are random in nature. The power available in random sea is expressed as

$P = 0.55\, H_s^2 T_z$ kW per metre length of wave crest,

where H_s is the significant wave height (defined as average of one-third of highest waves) in metres, and T_z the zero-crossing period in seconds. From this relation, for a significant wave height of 2 m and a zero-crossing period of 7 s, the available power is 15 kW m^{-1} of wave front.

Scientifically collected wave data along the Indian coast are scarce. A wave atlas published by the National Institute of Oceanography (NIO) in Goa based on swell data published in the Indian Daily Weather Reports (India Meteorological Department) gives the nation wide distribution of wave parameters. Scientific wave data, obtained using wave-rider buoys, are available for certain places along the Indian coast. These data give the precise information on wave heights and periods required to design the wave energy system. The average wave-power potential along the Indian coast is 5 kW m^{-1} to 10 kW m^{-1}. On the basis of scientifically collected data at Valliathura near Thiruvananthapuram on the Kerala coast[1], the average wave-power potential works out to be 13 kW m^{-1} for the site.

Research in India

Wave energy, which can make a significant contribution to the energy requirements of many countries with ocean coastlines, has received considerable attention. In India the Department of Ocean Development (DoD), Government of India, has sponsored wave-energy research at the Ocean Engineering Centre of the Indian Institute of Technology, Madras, from December 1982 onwards.

The first phase of the project was titled 'Scientific investigations on wave climate, wave regulation and wave power'. The main aim of this phase was to study the long-term wave climate along the Madras coast and to select a suitable wave-energy device. This study submitted its report[2] in February 1987, recommending a multipurpose energy-absorbing caisson breakwater as most suitable for the Indian coast. This was the result of a four-year theoretical and experimental study on the selected oscillating-water-column (OWC) device, and a bidirectional Wells air turbine.

Oscillating water column

A few hundred patents have been registered for different types of wave-energy devices throughout the world. The United Kingdom and Japan are the pioneers in this field, while Norway, Sweden, and the USA also have serious R&D work. Commander Masuda of Japan Marine Science and Technology Centre was the first to develop the OWC system with air turbine attached to light navigational buoys. OWC is the most international of the different device concepts in tapping wave energy.

The OWC system consists of a chamber in the sea exposed to wave action through an entrance at the bottom[3] or on the side. The air inside the chamber gets pressurized or expanded owing to wave action. Air movement through a small opening from or into the chamber, depending on the pressure inside, is used to drive an air turbine (Figure 1). This system is found to be the most promising.

The OWC chamber dimensions have to be selected to make it resonate to the wave. Wave height and frequency, however, vary from place to place. Even at a given place, they vary during the day, over different months, and from season to season. Since the dimensions of this device, made in concrete, cannot be changed, it is very important to see that the device absorbs wave energy equally well in the range of wave climate predominant at the site. This means that the device should have a very broad frequency bandwidth of absorption. Normally a resonating cavity like the OWC chamber has a single resonant frequency. However, research to increase the number of resonant frequencies to improve the efficiency of the system has proved successful.

In Norway an OWC with two guide walls in front of it, called a multi-resonant-oscillating-water-column (MOWC) device[4] has been developed. The guide walls, or harbours as they are known, produce additional resonances in the device. These additional resonant frequencies are within a frequency range of an octave of the normally occurring wave spectrum where more than 80% of the wave energy is available. Owing to the multiple peaks in the resonance curve the bandwidth of this passive resonator is improved over that of OWC.

Such an MOWC has been installed[5] on a rocky cliff projecting into the sea in Norway. The wall of the rock falls nearly directly to 60 m below sea level at this place. Hence the wave energy is not dissipated till it reaches the device. Such shore-based plants have the advantage of ease of construction and lower construction costs than off-shore plants. The maximum capacity of this prototype device is 500 kW. The power plant was built in 1985 by Kvaerner Brugs, but was knocked down[6] by a severe storm towards the end of 1988. However, the overall experience has been encouraging and this power plant is expected to be rebuilt.

Wave energy

The studies undertaken by the wave-energy group at IIT, Madras, initially were to study the wave climate off Madras on a long-term basis and to choose a suitable wave-energy device for the Indian coast. Our coast has a comparatively low wave-power potential and hence a system purely to tap wave energy may not be viable in the near future. However, there is a lot of potential for small fishing harbours all round the coast. Hence the present concept is to build multifunctional wave barriers that act as harbour walls on the one hand and also produce energy. Such a concept has the advantage that the overall cost of the system is shared by both the harbour-wall function and the energy-production function, thereby making the energy produced economical. Moreover, an energy-absorbing structure is a better civil-engineering design as it reduces the structural loads on the device. On the basis of studies on different devices it was concluded that the OWC system is the most promising one for India. Consequently developmental activities were concentrated on this device only. Mechanical energy conversion from the system was achieved by a suitable self-rectifying air turbine.

Since the air flow through OWC is bidirectional, the conventional turbines would require four valves for making the flow unidirectional towards the turbines. But provision of valves required to open and close with a period of 6 s to 14 s, corresponding to the wave period, will cause operational problems in the marine environment. A turbine that rotates in the same direction independent of air flow through it will be the most advantageous one for such an operation. Therefore a symmetrical-aerofoil concept, invented by Prof. Wells of Belfast University, UK, was taken up for further development and studies at IIT, Madras.

An important input for the design of wave-energy structures are reliable wave data. For scientific collection of wave data wave-rider buoys were deployed off Madras Harbour at locations of different sea depths and the wave climate was monitored from September 1984 for two years. Software for on-line processing of the wave data on an Apple personal computer has also been developed. On analysis of wave data from all along the country's coastline it was found that power potential along the Thiruvananthapuram coast was promising. The west coast also has the advantage of being less cyclone-prone than the east coast. One of the major problems of wave-energy design is that,

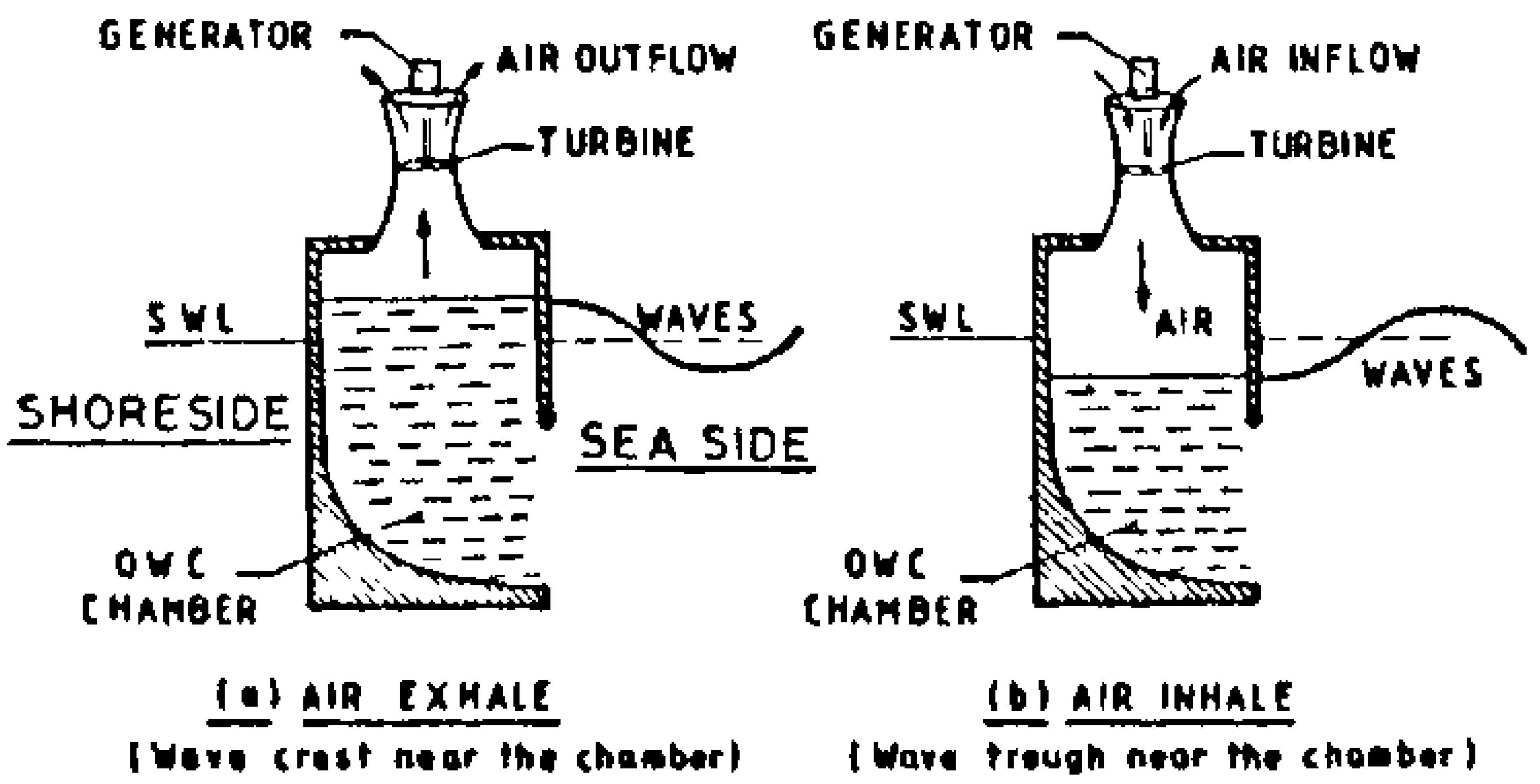

Figure 1. Principle of oscillating-water column wave-energy converter.

even though the power plant is designed to absorb energy from the normal wave climate, it has to withstand the severest of cyclones that might pass by during the life of the structure. This is one reason why offshore wave-energy plants are expensive, and hence onshore full-scale power plants are more popular.

During the first phase of the project the focus was on analytical and experimental studies to develop the shape and optimum dimensions of the OWC device. The analysis was done for two-dimensional wave conditions. Several models of different sizes were fabricated and tested by the project group to examine the influence of different geometries like rectangular and curved back walls, streamlined entry and harbour walls (MOWC) in 30-cm, 90-cm, 2-m and 4-m wave flumes. It was found that the MOWC device with harbour walls was the most promising.

Experimental optimization studies were then conducted on MOWC to optimize the harbour length for varying load conditions. To understand the absorption of energy from the device in a random sea, this harbour model was also tested under random wave conditions. A comparative performance of three model geometries tested[7] is shown in Figure 2. The ordinate represents the capture capability of the device and the abscissa the wave frequency.

Independently the Wells turbine selected for power take-off from the OWC air flow was studied. Different turbine models were fabricated and tested in a turbine casing with facilities for measurement of air velocity and pressure across the radius, as well as starting torque and speed. This unit was assembled and tested on a radial blower test rig. The performance characteristics of a prototype air turbine estimated from the model results[8] are shown in Figure 3. A detailed report of these scientific investigations was submitted to DoD in February 1987.

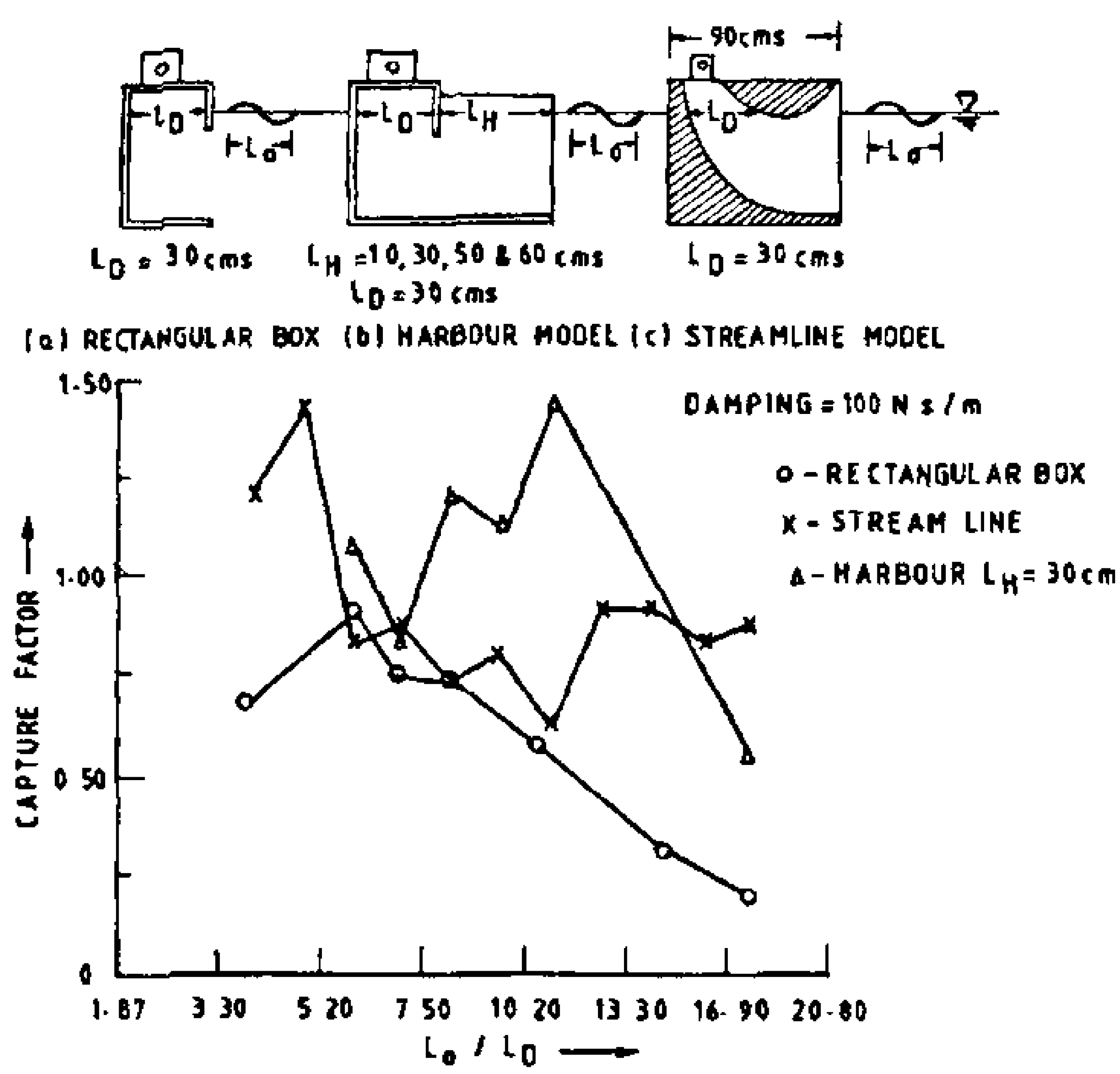

Figure 2. Comparison of performance of OWC test models with three generators.

Sea trial

The second phase of this project was the implementation of the sea trial of a 150-kW wave-energy system off the Thiruvananthapuram coast[9]. This involved the design and construction of a wave-energy caisson offshore, and design and fabrication of a 2-m-diameter Wells-type air turbine and a matching 150-kW induction generator. An instrumentation system using 40-channel data acquisition to monitor the performance of the device has also been fabricated.

The project group has considered basically two locations, one off Madras and the other off Thiruvananthapuram. For the first sea trial, the site off Vizhinjam Fisheries Harbour near Thiruvananthapuram has been found to be the best suited because of higher power availability, lower cyclone probability, and local infra-structural advantages. Site-specific model studies have been conducted[7] on a model of scale ratio 1:100 for the suitable design of the device to match the wave climate at the location. On the basis of these studies, a wave-energy caisson in concrete with overall dimensions of 13 m × 17 m × 14 m has been designed. (Figure 4)

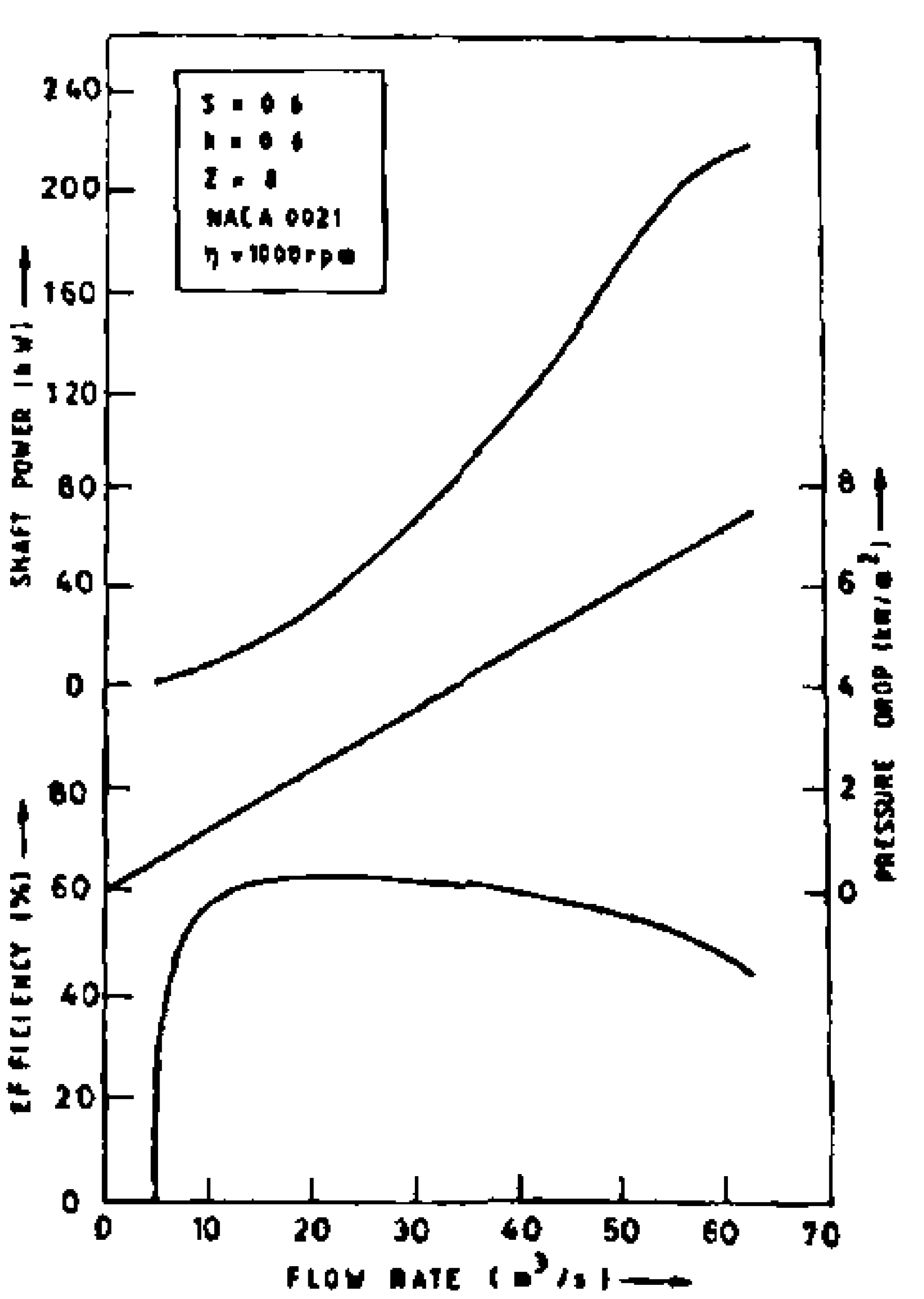

Figure 3. Predicted characteristics of prototype air turbine.

The first caisson was constructed successfully by ECC, the L&T construction group, but owing to an accident during the towing and seating operations it got grounded and was seated improperly. Subsequent wave action on this improperly seated caisson resulted in cracks on the concrete structure, as it was not designed for such a situation. The onset of monsoon further aggravated the situation and the caisson suffered damage beyond repair. (The caisson had been completely insured by New India Assurance.)

After a high-level technical review it was decided that the structural failure should not be a hindrance to the development of wave energy and that the project group should be given a go-ahead for a second caisson. Taking advantage of the previous experience the project group has redesigned the

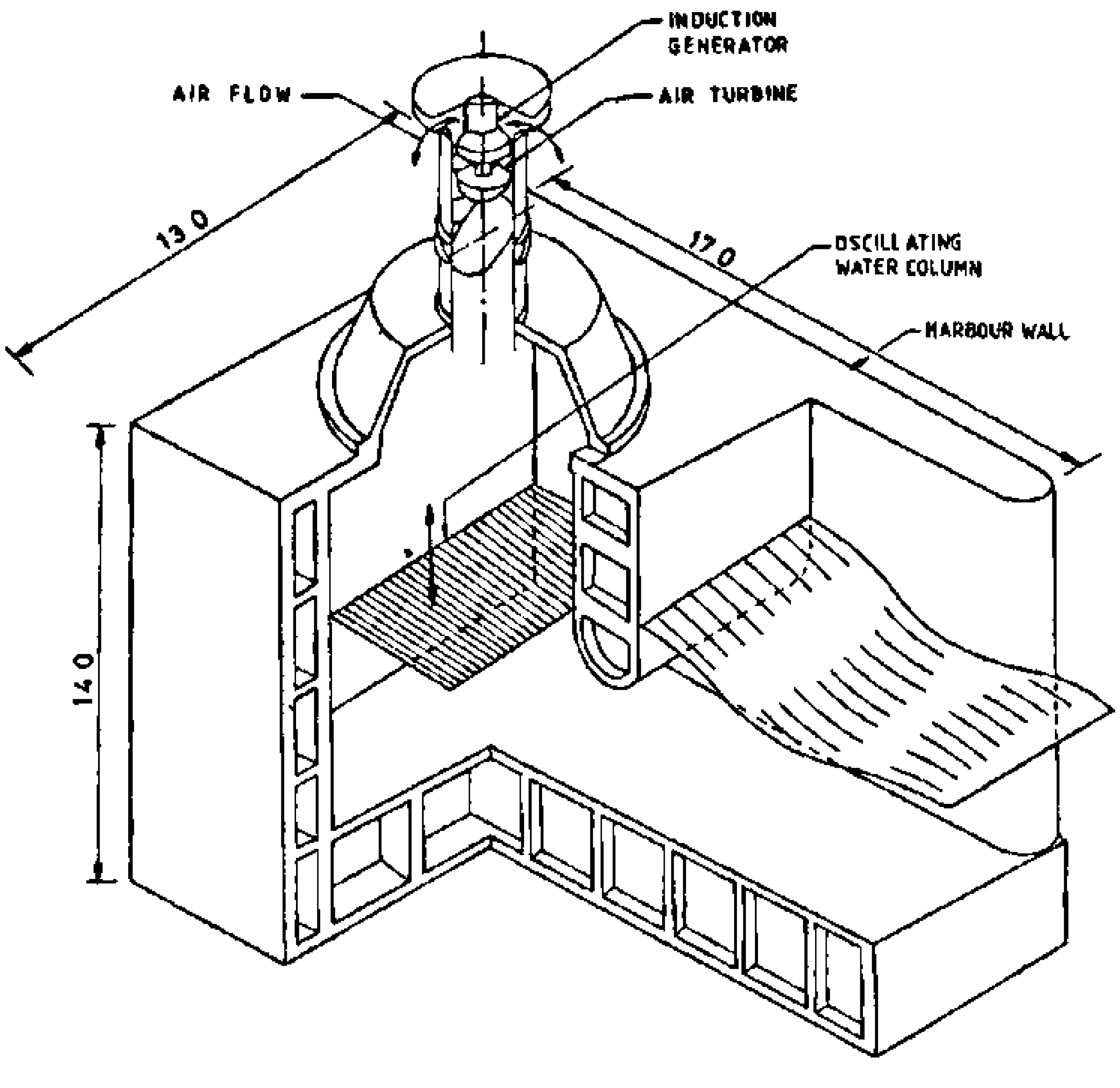

Figure 4. Wave power device.

caisson to take care of possible uncertainties. The section through the redesigned caisson is shown in Figure 5. Construction of the second caisson was completed by ECC in mid-December 1990 and the caisson was successfully towed to its final location and seated on the prepared sea bed on 31 December.

A steel foot-bridge has been erected between a breakwater wall and the caisson (Figure 6) and also a mechanical handling system on the caisson. A few mechanical components of the power module have already been installed over the dome of the caisson. A temporary gate used to provide stability during towing was successfully released on 23 March this year. [At the time of writing] The remaining parts of the power module are to be installed before May and the expected date of commissioning the wave energy power plant is June 1991.

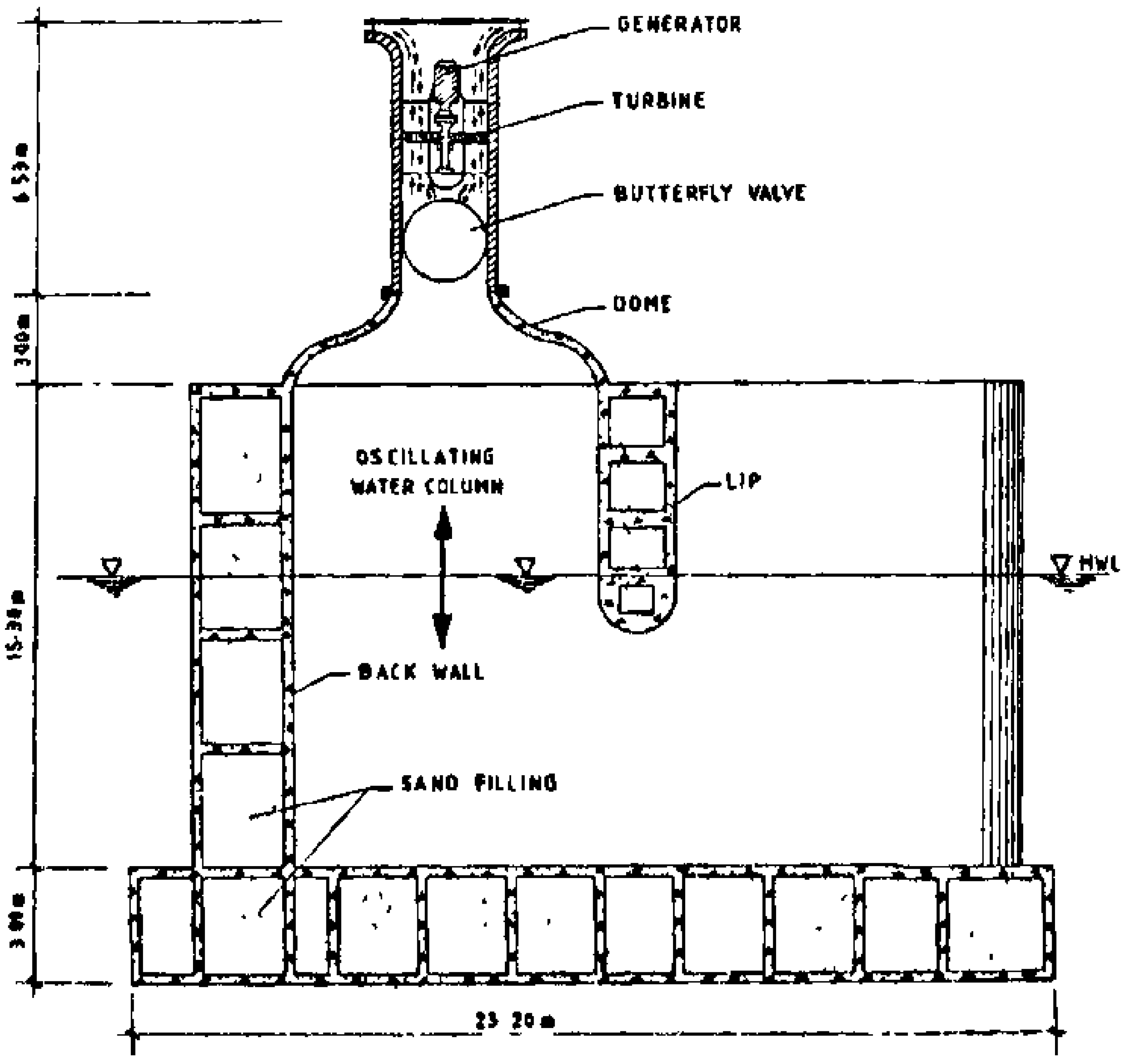

Figure 5. Section through wave-power plant.

Construction, installation sequence

The caisson construction and installation sequence is of major importance, particularly in view of the fact that no slipways or heavy-lift facilities are available at the site. Keeping in view the bathymetry, site conditions and, especially, availability of the harbour (Figure 7), the following methodology was adopted for the second caisson.

– The bottom concrete box (about 3 m high) of the caisson was constructed on a prepared bed, which was an excavated pit on the beach inside the harbour. This pit was continuously dewatered to keep the water table below construction level.

– The dewatering was stopped after this 3 m of construction was completed to make the box float. The sand bund between the pit and the harbour was breached.

– The box was then towed to the construction site inside the harbour and the construction of side walls was continued with the box afloat and the front gate in position.

– The caisson was then towed to its final location and sunk in position during calm weather on 31 December 1990, on a prepared sea bed consisting of rubble.

A bridge connecting the caisson to a breakwater wall just 45 m behind it has been erected (Figure 6). This provides the easy access required for monitoring the performance of this sea trial and also for transporting the power module to the caisson. A rubble toe protection has been given all around the caisson for better stability during extreme weather conditions. The power module to be installed on top of the caisson will be erected using the mechanical handling system.

Power module

The power module mounted on top of the caisson will consist of an air turbine of 2 m diameter coupled to an induction generator of 150-kW rating. The induction-generator system has been selected because it is economical and does not require rectification and inversion normally associated with a variable-speed alternator. The induction generator also has the advantage that it can be used as

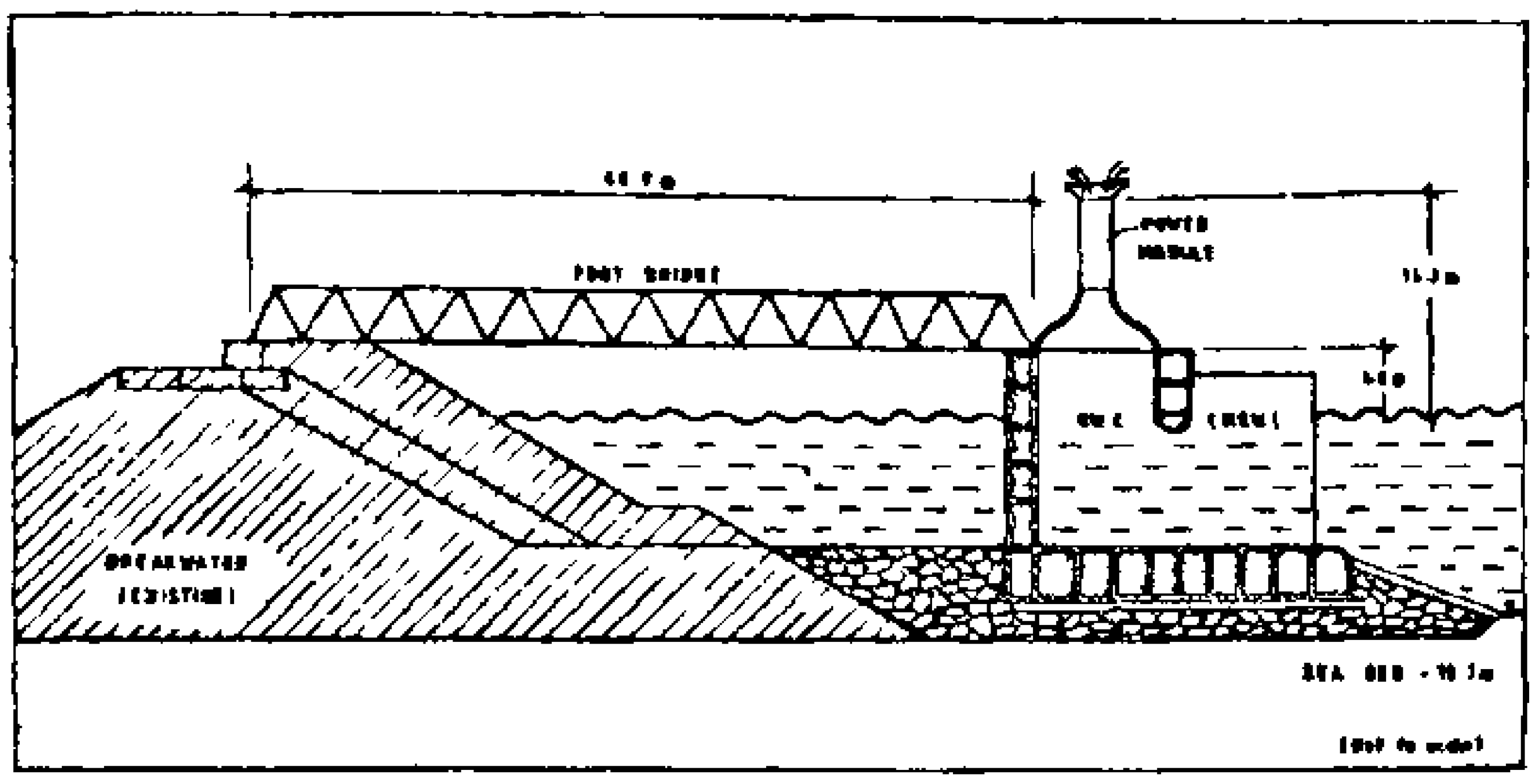

Figure 6. Cross-section of wave-energy device and breakwater. (Not to scale)

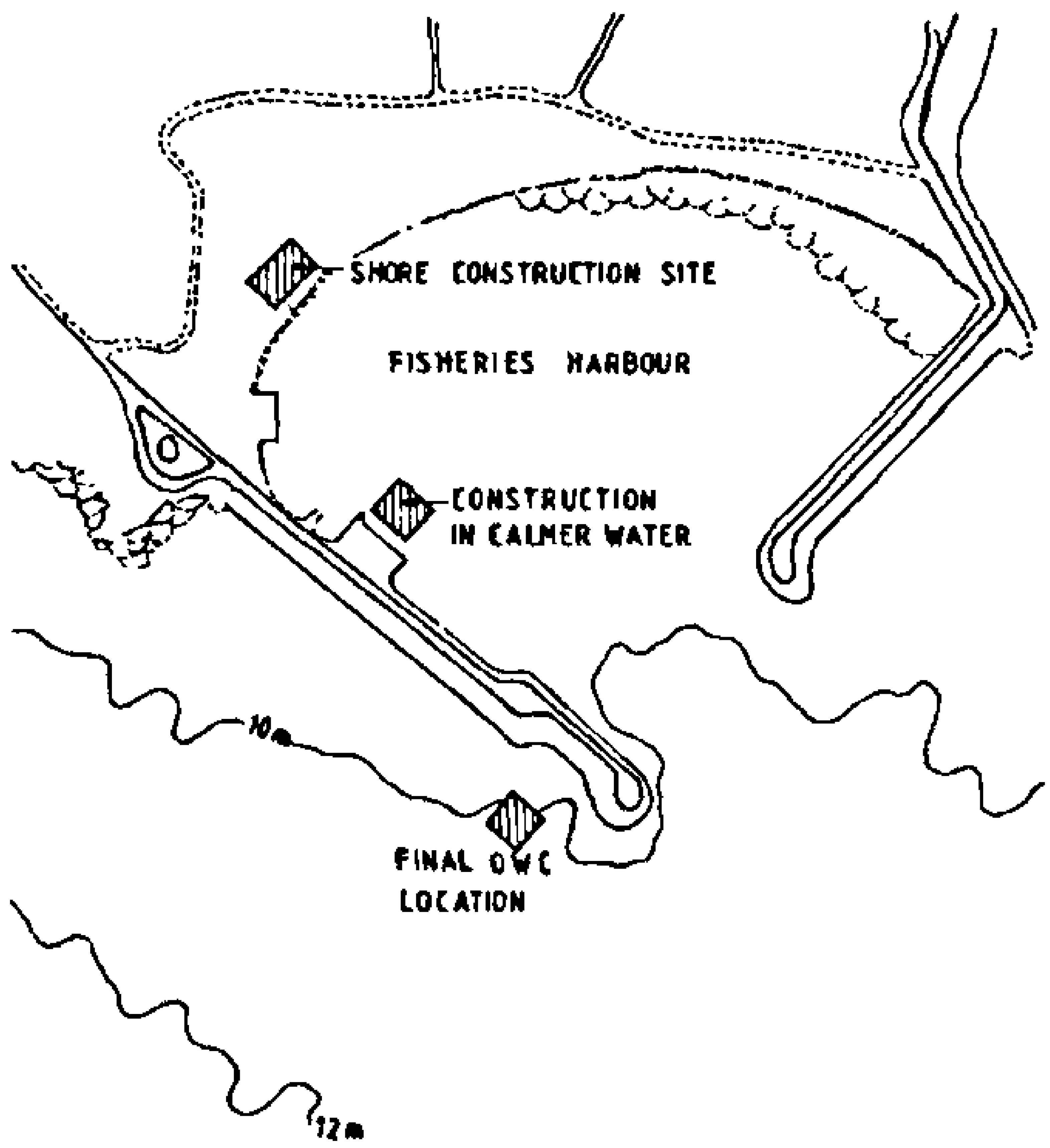

Figure 7. Vizhinjam harbour plan, with construction and installation sites of OWC.

a start-up motor for the air turbine when the wave heights are low. Thus the induction generator will always be connected to a grid, drawing power from mains when the turbine speed is below synchronous speed and pumping power to the grid when the turbine speed increases above synchronous speed. When the grid fails, the turbine will race and attain a high speed. To prevent this, a butterfly valve has been provided between the turbine and the caisson. This valve will automatically close when power fails (see Figure 5 for a section through the wave-power plant).

The butterfly valve has been supplied by Audco Valves, Madras, the 150-kW induction generator by Kirloskar Electric, Bangalore, and the turbine module by KCP, Madras. The total power-module integration is being done at KCP.

The wave-energy device will be delivering an average power of 75 kW during an eight-month period (April to November) and 25 kW during December to March. During the monsoon months of June to September, the device is expected to generate 120 kW, with a peak power of 150 kW.

The total cost of the project is estimated to be Rs 15 million. The total duration, which includes detailed engineering, construction, deployment, commissioning and monitoring, is three years. The system is estimated to deliver to the grid 445,000 units of electricity annually. Indigenous capabilities are available for the execution of this sea trial.

The sea trial is expected to lead to immediate commercialization. Ten units of the system, with a total capacity of 1.5 MW, can be built at the same location. The estimated cost of power varies from Re 1 per kWh to Rs 3.5 per kWh depending on whether the power generation is linked with a harbour construction or not. Many such harbours are in the offing on the Indian coast.

1. Thomas, K. V. and Baba, M., Mahasagar-Bulletin of the National Institute of Oceanography, 1983, **16**, 415.
2. 'Final report on scientific investigations on wave climate, wave regulation and wave power', Report submitted to DoD by the Wave Energy Group, Ocean Engineering Centre, Indian Institute of Technology, Madras, Feb 1987.
3. Meir, R. A., in Proceedings of the Wave Energy Conference, London, 1978, p. 35.
4. Oddbjorn, Malmo, Ph D thesis, University of Trondheim, Norway, 1984.
5. Bonke, Knut, 'Building of wave energy power stations in Norway', Kvaerner Brugs Multiresonant Oscillating Water Column Report, May 1986.
6. Carstens, Torkild, 'Wave power: from the laboratory to practice', *Power Generation Technology 1989*, Sterling Publications International, London, 1989.
7. Koola, Paul Mario, Ph D thesis, IIT, Madras, 1990.
8. Swaminathan, G., Ph D thesis, IIT, Madras, 1990.
9. 'Sea trial of a 150-kW wave energy device off Trivandrum coast', Project Report submitted to DoD by the Wave Energy Group, Ocean Engineering Centre, Indian Institute of Technology, Madras, Sept. 1987.

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