CHAPTER 356

COST EFFECTIVENESS OF WAVE POWER EXTRACTION AT EROSIVE COASTS

HIDEO KONDO*

ABSTRACT

Cost of wave power extraction is investigated for the coasts where erosion has been continuing without suitable countermeasures. By a wave power cxtraction, a shoreline accretion is expected due to the mean sea level drop. Cost effectiveness is discussed with the concept of total cost instead of the generation cost only.

INTRODUCTION

Wave power utilization has not essentially been commercialized yet except small size navigation buoys though remarkable progress has been achieved in the last two decades. The reason is simply that the cost of electricity from waves is still much higher compared with those from fossil fuels and of nuclear. However, it is required to remove unfavorable gases like CO_2 etc. exhausted in the process of burning fuels from the standpoint of global environmental protection. This process needs an additional cost which we may call the environmental cost. The cost is known presently to be no less than that of power production itself.

Meanwhile continuous retreat of eoasts by wave and meteorological tidal actions has become serious at most coastal countries in the world. Coastal engineers have worked extensively to solve the problems by constructing coastal structures or by feeding sand in eroding beaches. Extraction of wave power decreases apparently the transmitted wave power shoreward and will weaken beach erosion with similar actions as the above two methods do.

In thc present study the author proposes an approach to evaluate the total cost as well as the production cost of wave power extraction at erosive coasts which is subsequently examined for case studies.

* Department of Civil Engineering & Architecture, Muroran Institute of Technology, 27-1 Mizumoto-Cho, Muroran, Hokkaido, 050 Japan

TOTAL COST ESTIMATION

The total cost Pt (¥ / kWh) consists of the market or generation cost Pm, the environmental cost Pe and the social cost Ps as (Kondo et al,1991 and 1993),

$$Pt = Pm + Pe + Ps \tag{1}$$

Pm is estimated with conventional procedures. Defining $E_{p,j}$ as the environmental value of jth factor, Pe, the cost to repair the environmental damages occurred in power production process is estimated as,

$$Pe = \Sigma \Delta P_{i,j} = \Sigma \frac{\partial E_{p,j}}{\partial x_i} \Delta x_i \tag{2}$$

In the above equation $\Delta P_{i,j}$ is the repair cost brought by the variation of jth environmental factor by the variation of the environmental factor i in the course of production. Pe of fossil-fired electricity includes expense of removing and treatment of harmful waste gases such as CO_2.

The environmental cost is positive for the cases of fossil-fired and nuclear powers. For the cases of renewable energies it can be minus when they bring better environment than that without extraction. The social cost Ps may be the expenses of moving houses and structures, compensation for damaging fishing industry, and the expenses dispatching troops to keep the sea-lane safe to tankers for imported oil, etc.

WAVE POWER BUDGET AND DEFORMATION

The incident wave power through the extracting device and structure is divided to the reflected, the power extracted, the loss by extracting process and structure, and the transmitted shoreward. The ratios of these depends on types of device, structure and the operating conditions. Approximate figures for the extracted and the transmitted are estimated for later calculation as in the following.

TABLE-1 WAVE POWER BUDGET (Extracted / Transmitted)

TYPE OF SYSTEM	IN OPERATION	STOPPED
Floating (OWC)	30 / 50	0 / 100
Bottom Fixed(Pendulor)	50 / 20	0 / 50

SHORELINE ACCRETION BY MSL DROP

Continuous retreat of shoreline by wave and meteorological tidal action has become one of the most serious problems in all coastal countries. It has been accelerated by the remarkable trend of mean sea level (MSL) rise. The power extraction from waves in offshore or inshore zone decreases the incident power and the height of transmitted wave and the size of MSL.

We know that a MSL rise brings a retreat of shoreline more than that anticipated from the static geometry in sandy coasts. Thus we may apply the relationship between the MSL rise versus the shoreline retreat to MSL drop at beach versus shoreline accretion by the wave power extraction. Several approaches have been proposed for the relationship between MSL rise and beach retreat we will use the one by Mimura et al (1994) for later calculation.

The environmental cost for the wave power extraction is minus since it makes natural beaches wider or saves constructing revetments on shores.

PENDULOR WAVE POWER EXTRACTOR

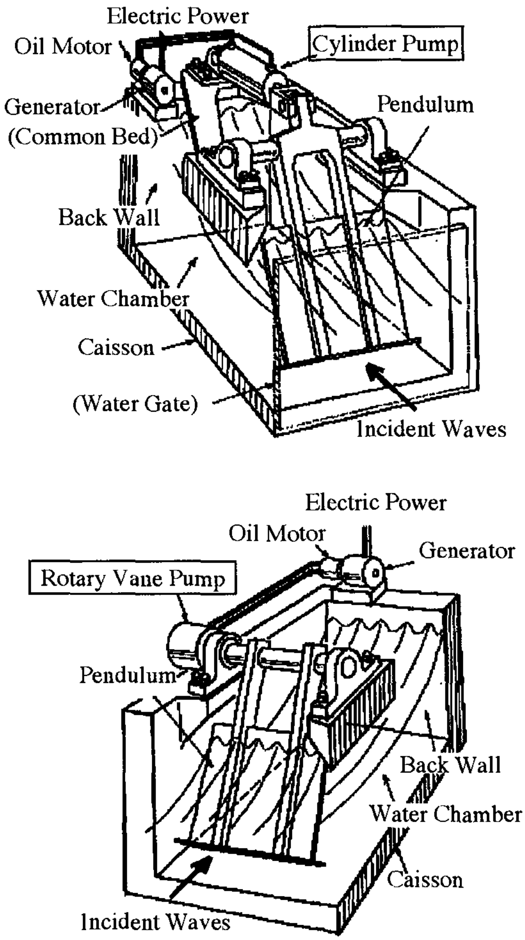

Fig.1 Pendulor Wave Power Extractor in Caisson

We have studied Pendulor power extractor of bottom standing type which can be installed in upright caisson breakwaters since 1980 (Kondo et al, 1984, Yano et al,1985, and Watabe, 1993). Two basic types of it are sketched in Fig.1. It consists of pendulum plate in a concrete caisson with seaside open and a hydraulic power transmission system. A back wall, two side walls and the bottom plate of caisson together with the pendulum plate forms a water chamber where a standing wave system is generated by oscillation of the plate.

Originally it had been developed as the cylinder pump type (the upper one in Fig.1). Laboratory and field experiments has proved it to have high efficiency and to lower the cost compared with the other kinds of extractors (Watabe, 1993).

The rotary pump type, the lower one in Fig. 1, was proposed later and has been being studied (Watabe et al, 1996).

STUDIED LOCATIONS

Three locations of Japanese coast which are typical ones at Hokkaido, Touhoku and Kantou area, respectively of different wave climate have been chosen to estimate the total cost for electric power production employing Pendulor system.

TABLE -2 WAVE CLIMATE OF THREE TYPICAL COASTS

COASTS (Oceans)	AVERAGE WAVE			DESIGN WAVE	
	H1/3	T1/3	W	H1/3	T1/3
Hokkaidou (Japan Sea)	1.1(m)	4.9(sec.)	5.3(kWh/m)	7.5 (m)	12.0(sec.)
Touhoku (Pacific)	1.0	7.4	6.3	7.5	14.0
Kantou (Pacific)	1.5	7.4	11.5	11.0	15.0

COMPUTATION PROCEDURE

The generation or market cost Pm was computed according to a conventional way for the case of electricity in Japan. Table-3 presents the computational process for the case of KANTOU coast.

The environmental cost has been computed from the two approaches:

(a) From the difference of expenses to construct a revetment at shoreline.

The revetments are designed for the two cases of with and without power extraction to the design waves shown in Table-2. The expense to construct a revetment is estimated from which Pe is computed.

(b) From the expense of filling the eroded shores every year.

The volume of beach eroded by the average annual wave shown in Table-2 is estimated for each location. Then the cost of sand filling to eroded shore is estimated from which Pe is computed.

TABLE - 3 Estimation of Market Cost, *Pm* (KANTOU COAST)

(1) DESIGN CONDITION

Water Depth: 10 m below LWL

Tidal Range: 1 m

Mean Wave Power: 11.5 kW/m

Design Wave; $H_{1/3}$ = 11 m, $T_{1/3}$= 15 sec.

Extrator: Pendulor in Bottom Standing Caisson

Overall Efficiency: 0.5

Caisson: Unit Length of 20 m

Rating Output per Unit: 11.5∗ 20∗0.5 = 115

(2) EXPENSE AND COST (Debt Financing Rate 6 % per Year)

A: Cost of Caisson = 12 (M¥/m)∗ 100= 1200 M¥

B: Cost of Generating System = 6 0M¥ ∗ 5 = 300 M¥

C: Total Construction Cost = 1500 M¥

D: Specific Cost = C/ Output = 1500/575 = 2.6 M¥/kW

E: Fixed Cost = Total Cost ∗ Equivalent Coefficient

= 1500 ∗ 0.07581 = 114 M¥/Year

F: Operation Cost = B ∗0.05 = 15 M¥/Yea

G: Expenditure = E + F = 129 M¥/Year

H: Amount of Generated Electricity

= Output 24hr ∗ 365day ∗ Workig Rate

= 575∗ 24 ∗ 365∗ 0.58 = 2.72 ∗ 10^6 kWh/Year

(3) MARKET COST

I: Cost of Electricity = G/H = 44 ¥/kWh

The result of estimation is shown in Table 4 which reveals that Kantou area shows the lowest market cost, Pm of 44(¥/kWh). It is still about three times than that of oil-fired as of 1994. It is sensitive to the debt financing rate which is 6 % in present estimation. For the case of 2% rate, Pm decreases to 30(¥/kWh).

The total costs, Pt, however, becomes close to it at Kantou area (Table - 5). For the case of the debt ratio of 2 % it becomes less than that of oil-fired.

TABLE - 4 COST OF ELECRICITY FROM WAVE in ¥/kWh

LOCATION	Pm	Pe	Ps	Pt
HOKKAIDOU	62	(a) -18	1	45
	40	(b) - 5	1	58
TOUHOKU	59	(a) -16	1	44
	38	(b) -11	1	49
KANTOU	44	(a) -11	1	34
	30	(b) -13	1	32

In addition to the wave power, the other two ocean energies, namely current and tide, and wind are also investigated for the cost analysis at promising locations in Japan, the costs of which are considerably higher than those of wave power as shown in Table-5, except wind. -5.

TABLE - 5 COST OF ELECTRICITY BY RENEWABLE ENEGIES IN ¥ /kWh (Ratio to Oil-Fired)

ENERGY	LOCATION	Pm	Pe	Ps	Pt
WAVE	KANTOU	44	-13	1	32 (1.3)
CURRENT	TSUGARU STRAIGHT	33	3	1	37 (1.5)
TIDE	ARIAKE BAY	73	3	2	78 (3.1)
WIND	MURORAN	48	-14	1	35 (1.4)
OIL - FIRED	KANTOU	12	12	1	25 (1)

CONCLUSIONS

The present study has revealed that wave power utilization at erosive coasts is found to be a promising way to get inexpensive clean energy in Japan and may be so for most coastal countries though the cost depends on heavily domestic natural and economical condition. The utilization will restore invaluable fossil fuels, and precious beaches for the future generation.

ACKNOWLEDGMENTS

The author would like to thank Dr. Tomiji WATABE, T-Wave Consulting Volunteer and Mr. Senji OSANAI, formerly Manager of Cold Region Port & Harbor Engineering Research Center for their constant support to the wave power study at Muroran Institute of Technology.

Thanks must go to Miss Hiromi HAMATSU, former student who had done a part of this study for her B. E. Thesis and Mr.Noriyuki OOTA, the technical staff who assisted for preparing the manuscript at Department of Civil Eng. & Architecture of the institute.

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