deaeration to extract noncondensible gases, warm seawater is flash evaporated in a vacuum chamber. Desalinated water vapor drives a steam turbine which in turn drives a generator. The water vapor is then either condensed in a direct contact condenser and discharged to the sea, or condensed with a surface condenser producing desalinated water as a byproduct. The latter feature is particularly attractive in arid tropical islands. A 165 kw open cycle OTEC experiment is planned to be conducted through a cost-shared project between DOE and the Pacific International Center for High Technology Research at the Natural Energy Laboratory of Hawaii, Kailua-Kona, Hawaii (Lewis, 1987). After a series of open cycle component evaluations (presently underway), an apparatus will be constructed and used to validate system performance predictions, identify technical issues and obtain data scalable to future commercial size plants. These experiments will be supported by an upgraded seawater supply system recently installed at the site (Lewis, 1988). This system included the installation of a 1.0 m diameter cold-water pipe capable of delivering 840 l/s (410 l/s to the OTEC facility, 430 l/s to State mariculture projects). The pipe represented the largest diameter, longest (2,060 m) pipe tranversing the steepest slopes ever spanned.

Ocean Current Energy Conversion

In waters adjacent to the United States, the significant ocean current resource is limited to the Florida Current and the Gulf Stream off the southeast coasts. Estimates of extractable energy from these sources vary from 10,000 to 25,000 MW. Two axial flow rotary current energy systems have been developed by U.S. companies. Aerovironment, Inc. with DOE support, developed a ducted hydraulic turbine called Coriolis for applications to the Florida Current (Figure 12). Rim suspended two stage counter rotating catenary rotors were designed to feed energy to rim-mounted generators. Completed research included hydraulic performance evaluation of the rotors, Analyses of anchoring and mooring configurations, and system economic studies (Lissaman, 1979).

A similar device was developed by the UEK Corporation and is illustrated in Figure 13 (Vauthier, 1984). Energy in a flowing stream is converted to mechanical energy by a two-stage turbine. A radial outflow stage is followed by an axial flow stage. The inlet flow is through a venturi-shaped 3.7 m diameter shroud which concentrates the flow energy. The entire mechanism is tethered by cables so as to be held in the current stream, or suspended below a support platform. The device has been tested in Chesapeake Bay by towing it behind a tugboat. The New York State Power Authority has purchased one unit for evaluation.

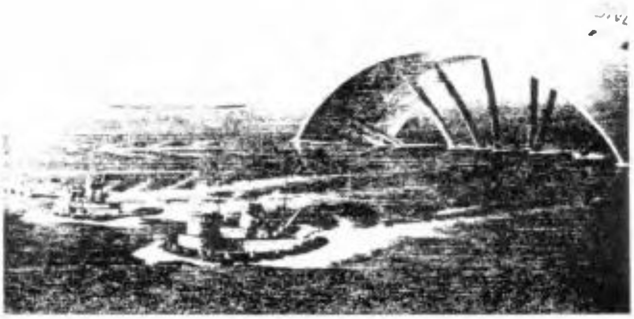

Figure 12. The Aerovironment, Inc. Coriolis Ocean Turbine

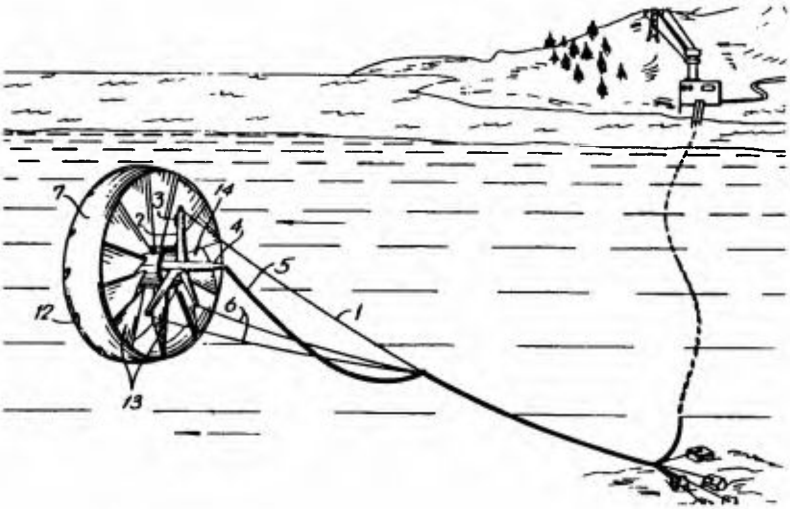

Figure 13. The UEK Corporation Underwater Kite

Conclusions

There is an abundant resource for ocean energy development in waters adjacent the United States and its territories. There is a high potential for extraction of energy in these waters from ocean waves, ocean thermal gradients, tides and ocean currents at selected sites. However, the existence of these resources does not imply immediately usable energy, since any device built to operate in these environments must be competitive with conventional land-based energy producing systems. Nevertheless, at some remote sites where conventional generation of power is relatively expensive, it is possible that an ocean energy source would provide economic power in the near future.

References

Focas, D., "Straflo Turbines for Tidal Applications," Proceedings of the 2nd International Symposium on Waves and Tidal Energy, Cambridge, England, 1981.

Hagerman, G.M. and Gordon, C.K., "Conceptual Design of a Prototype 500 KW Contouring Raft Wave Energy Conversion Device," Proceedings of the Renewable Energy Technology Symposium and International Exposition, Anaheim, California, 1987.

Hicks, D.C., Pless, C.M. and Mitcheson, G.R., "DELBUOY Wave Powered Seawater Desalination System," Proceedings of the Marine Technology Society Oceans' 88, Baltimore, Maryland, 1988.

Hopke, H.H. and Grant, A.D., "The Wave Energy Module," Proceedings of the 4th International Conference on Energy for Rural and Island Communities, Inverness, Scotland, 1985.

JAMSTEC, "Open Sea Trials," International Energy Agency Report on Development of Wave Power by Japan Marine Science and Technology Center, Yokosuka, Japan, Vol. 4, 1987.

Lewis, J.F., Trimble, L. and Bowers, J., "Open Cycle OTEC Seawater Experiments in Hawaii," Proceedings of the Marine Technology Society Oceans' 87, Halifax, Nova Scotia, 1987.

Lewis, L.F., Van Ryzin, J. and Vega, L., "Steep Slope Seawater Supply Pipeline," Proceedings of the 21st International Conference on Coastal Engineering, American Society of Civil Engineers, Malaga, Spain, 1988.

Lissaman, P., Radkey, R.L., Thompson, D.I. and Mouton, W.J., "An Evaluation of Hydroelastic and Dynamic Behavior of Key Components of the Ocean Turbine System," Report ET 20518/1, Aerovironment Corp. for U.S. Department of Energy, Washington, D.C., 1979.

Main, C.T., "Half Moon Cove Tidal Project Feasibility Project," Chas. T. Main, Inc., Boston, Massachusetts for U.S. Department of Energy (Report FC07-801D12089), Washington, D.C., 1980.

McCormick, M.E., "A Conceptual Design of a Counter Rotating Wave Energy Conversion Turbine," U.S. Naval Academy (Report EW-19-78), Annapolis, Maryland, 1978.

McCormick, M.E., Ocean Wave Energy Conversion, Wiley Interscience, New York, New York, 1981.

OTC "40 MW OTEC Power Plant, Final Technical Report," Ocean Thermal Corporation, New York, New York for the U.S. Department of Energy (Report DE-AC02-78ET-20480), Washington, D.C., 1984.

Pless, C.M., "Seawater Powered Desalination," Proceedings of the Offshore Mechanics/Deepsea Systems Symposium, American Society of Mechanical Engineers, Fairfield, New Jersey, 1982.

Q Corporation, "The Experimental and Theoretical Evaluation of an Engineering Model of the Tandem Flap Wave Energy Conversion Device," Q Corporation, Troy, Michigan, 1985.

Richards, D. and Weiskoff, F.B., "Studies and Testing of the McCormick Pneumatic Wave Energy Turbine with Some Comments on PWECS," Proceedings of the Symposium on the Utilization of Ocean Waves, American Society of Civil Engineers, La Jolla, California, 1987.

Sea Solar Power, "Ocean Thermal Energy Conversion, An Option for Puerto Rico, Review of Sea Solar Power, Inc. Proposal," Southern States Energy Board, Atlanta, Georgia, 1987.

Scher, R.M., "A Study of Flap Type Wave Absorbing Devices," Q Corporation, Troy, Michigan and University of Michigan, Ann Arbor, Michigan, 1985.

Vauthier, P. and Dement, D.K., "Ocean Current Electric Generation, the Underwater Electric Kite," Proceedings of the 5th World Hydrogen Energy Conference, Toronto, Canada, 1984.

Wayne, W.W., "Tidal Power Study for U.S. Energy Research and Development Administration," Stone and Webster Engineering Corporation, Boston, Massachusetts, 1977.

Wilke, R.O., "The Tandem Flap Wave Energy Conversion Device Great Lakes Experimental Test Program," Q Corporation, Troy, Michigan for Solar Energy Research Institute (Report ZX-6-06000-1), Golden, Colorado, 1985.

CHAPTER 73

LONG WAVES IN A SPANISH HARBOUR

Jose C. Santás López (*)
Gregorio Gómez Pina (**)

ABSTRACT

Short and Long Wave data recorded in Bilbao Harbour (Spain) have been analyzed in order to study water movements at the inner basins under storms conditions . Some of the trends obtained in prototype have been correlated with model test (regular long wave and irregular short waves) .

This harbour has been chosen for this research on the one hand because of tha availability of the physical model and on thge other hand because of the means provided by the Bilbao Port Authority

1.- INTRODUCTION

For a long time, there has been a great concern to know the behaviour of harbour basins with regard to long waves. These long waves can induce resonant effects in water bodies, and consequently, in moored ships. As a result, moored ship operations become much less efficient.

After the well known Longuett-Higgins'article, in 1964 (Longuett-Higgins, 1964), the amplitude of the long waves associated to wave grouping (β) , was calculated. The expression for this magnitud was the following :

$$\beta = - 3 \cdot g \cdot a^2 / 2 \cdot \omega^2 \cdot h^2$$

Where : a = short wave amplitude ; $\omega = 2\pi/T$; T = wave period ; h = water depth.

The wave set-down period (T_g) corresponds to the wave grouping, being the former a function of the wave grouping grade and the wave peak period (T_p). The experimental evaluation of T_g can be done in different ways : based in the number of waves in a group (Sand, 1982 a), from the SIWEH spectrum (Funke & Mansard, 1980), and also, as a mean value of the up-zero crossing period, obtained from the SIWEH spectrum T_z (SIWEH) (Iwagaki, 1986).

This set-down wave is feeded by a second order mechanism from the short wave, in different ways (Bowers, 1977). In a harbour, this long wave will as a bounded long wave (BLW), as a free long wave produced by the energetic inbalance at the harbour entrance, due to water

(*) Head of the Oceanog. Eng. Div. , CEPYC-CEDEX , Madrid .
(**)Head of the Exper.Harbour Div. , CEPYC-CEDEX , Madrid .
Antonio López st., 81 . 28026-Madrid . Spain

depth differences (FLW) , and as caused by wave breaking phenomena on a beach , located near a harbour , such as surf-beats and edge waves.

The resulting long wave can be in resonance with the different harbour basins if T_g is close to the natural period of the basins, giving rise to resonant amplifications.

The BLW has been widely studied and its parameters have been correlated with waves characteristics outside the harbour, for both unidirectional and directional waves, having a kind of energy spreading $D\theta$ for the latter (Sand, 1982 a, and 1982 b). An application of the BLW parameters was carried out for Sines Harbour by Vis et all, 1985.

This piece of work shows the results obtained in Bilbao Harbour where the BLW, FLW, and resonant amplifications were simultaneously detected under severe storm conditions. Regular long wave model tests were carried out to characterize harbour resonant responses. Also, irregular wave model tests were performed to compare trends in the prototype and model, in regard to long wave energy transfer outside and inside harbour basins.

2.- FIELD DATA ANALYSIS

Waves outside the harbour were recorded in a Datawell Waverider , located at a water depth of h=50 m (Fig.1). The signal transmitted by the buoy is collected at a station where it is recorded every 1 ó 3 hours, depending on whether there is an "alarm signal" or not (wave conditions such as H_s >4 m., and T_s > 16 seg). The recording equipment consists of a HP-86 computer. The 5,000 data of each record are stored on a hard disk (Dt = 0.5 seg), transferred later to a moveable disk, and sent to the CEPYC, in Madrid. Sampling characteristics were chosen after studying the stationary and representative conditions of the calculated statistical and spectral

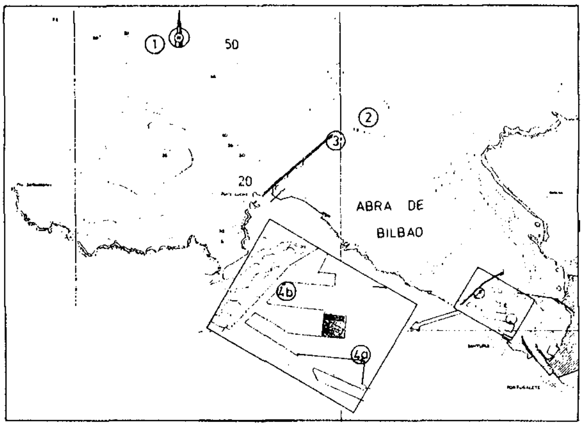

Fig 1: Position of measurement systems : Outside Waverider (1) ; "Morro" Waverider (2) ; Metheorological Station (3) and Pressure Sensors (4a & 4b) .

parameters (A.Fernandez , 1988). A bdeep description of this system is shown in Martinez , Santás and Sanz , 1988 .

Long waves were registered by a pressure sensor, manufactured at the CEPYC, consisting of a differential thin film strain gauge, located in a watertight chamber, filled with silicone oil. The outer connexion was made by two openings in the sensor. One of these openings was feeded by a hydraulic filter to remove the tide long wave. The filter characteristics are : 6 dB high pass, crossing frecuency 1/(6hr). The high frecuency removing is done by the hydrodynamic attenuation of the water column in the sensor, installed at a water depth of 6 meters.

The information supplied by this pressure wave sensor was digitalized (Dt= 2.5 seg), using series of 4096 points, and recorded on other HP-86 system, transferred to a moveabl disk system later, and sent to the CEPYC, in Madrid.

The data analysis carried out later , based on the above mentioned information, is summed up bellow :

A) Waverider :

- Standard statistical parameter calculations
- Spectral calculations : FFT previous filtering (T<4 seg, and T>25 seg), and later smoothing (18 freedom degrees). The resulting time series will be called "*Outside Short Wave*" (OSW), and its corresponding spectrum S(OSW).

- SIWEH calculations : long wave time series and spectrum , statistical analysis of typical values, estimation of T_{g} and grouping factor GF (Funke & Mansard, 1980). The SIWEH long wave will be called "*Outside Long Wave* " (OLW), and its corresponding spectrum S(OLW).

B) Inner Wave gauge

- Surface wave recomposition, in amplitudes and phases, for the 10 min. > T > 10 sec. band, using the hydrodynamic wave attenuation factor K, given as :

$$K = \cosh (k.h) \, / \, \cosh (k.b)$$

where h = instantaneous water depth ; k = wave number ; b = distance from the bottom.

A frecuency filter transference function was used to correct FFT data. Short and long wave band differentiation were defined in the following way :

Long wave : 1/(10 min) < f <0.04 Hz (ILW)
Short wave : 1/(35 seg) < f <0.1 Hz (ISW)

Typical statystical parameter calculations, for both time series, called "Inside Long Wave" (ILW), and "Inside Short Wave" (ISW)were made

Spectrum calculations for both time series with a previous Bingham smoothing, and a later Bartlett smoothing . The number of freedom degrees for ISW and ILW were 30 and 18, respectively.

2.1.- PROTOTYPE WAVE DATA STORAGE

Wave data storage began in March, 1986. The long wave pressure gauge was initially placed in position 4a (Figure 1), changing this position to 4b, in March 87, where it is still placed.

It was considered interesting to analyze the data only where long wave height was higher than 10 cms. The storms analyzed corresponded to the following days :

Position 4a : a) March 24-27, 1986
Position 4b : b) April 20-21, 1987; c) September 4-5,1987 ; d)January 22-26, 1988; e) January 30-February 12,1988; f)March 16-17, 1988.

Figure 2 shows the time series for H(z,s), corresponding to the Waverider (OSW), the inside short wave (ISW), and the inside long wave (ILW) for the stage a).

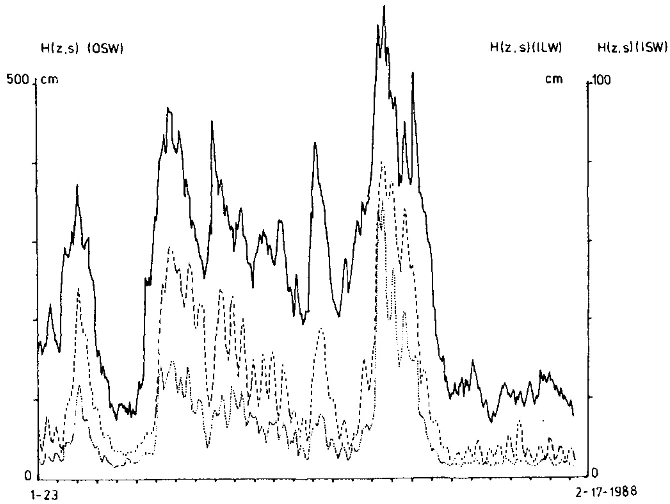

Fig.2 : Wave Time Series H(z,s) : (______) Outside Short Wave (OSW), (-----) Inside Short Wave (ISW), (.......)Inside Long Wave (ILW) . Data from 1.23.1988 to 2.17.1988 .

3.- RESULTS OBTAINED FROM PROTOTYPE MEASUREMENTS

First of all the short wave data OSW and ISW were correlated and compared. Two interesting aspects were found :

-The correlation between significant wave heights H(z,s) inside (ISW), and outside (OSW) was in the range of 8 and 13% (fig.3a), depending on the wave period.

- The significant and mean wave periods T(z,s), and T(z) have a small increment, between 7% and 9%. This fact is also found for the peak period T_p (Fig. 3b).

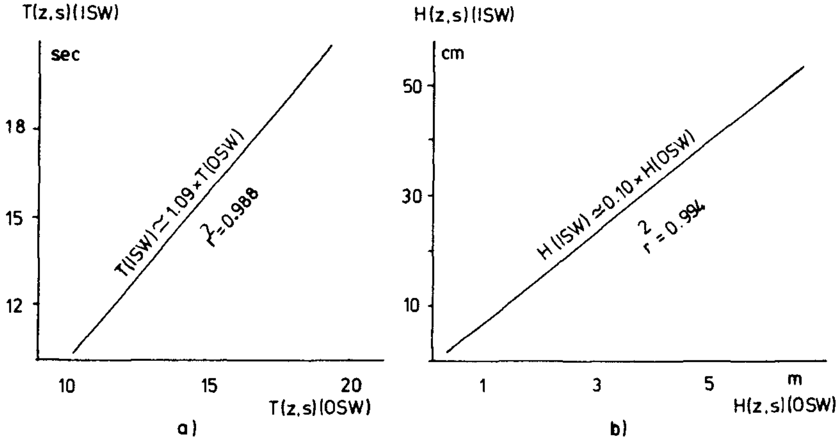

Fig. 3 : Comparison of Statistical Results between ISW and OSW
3a) : T(z,s); 3b) : H(z,s).

As it will be explained later, similar trends appear in the physical model. Moreover, the values obtained for wave agitation coefficient inside the harbour, from both mathematical and physical models, appear to be within the above mentioned range for H(z,s).

In regard to the long wave measured (ILW) inside the harbour and the short wave outside it (OSW) , the main findings are as follows :

- The correlation between H(z,s), (OSW), and (ILW) depends very much on the measurement area, which is indicative of some resonant mechanism. For location 4a(Fig.1) this correlation was found to be

$$H(z,s)\ (ILW) = 1.586 \cdot 10^{-3} \cdot [\ (H \cdot T)\ (OSW)\ /\ h\ ]$$

This kind of correlation fits better than the quadratic one used in Sand's, with data obtained from the stage a). However, for position b), which is more favorable for resonant effects due to its basin location, the correlation was found to be (with $r^2 = 0.8050$) :

$$H(z,s)(ILW) = 0{,}0732 + 4{,}841 \cdot 10^{-5} \cdot [\ (H,T)^2\ (z,s)\ (OSW)\ ]\ /\ h$$

Whereas for a best fit of (H,T), the following formula is obtained ($r^2 = 0.72$) :

$$H(z,s)(ILW) =- 0.1177 + 6{,}319 * 10^{-3} \cdot [\ (H,T)\ (z,s)\ (OSW)\ ]\ /\ h$$

This last expression shows a degree of five times better for position 4a than for 4b (Fig. 4a and 4b). This explains a resonant effect for the long wave energy.

The unexpected fact that the quadratic expression for (H,T) is not clearly accomplished , could be explained by considering an

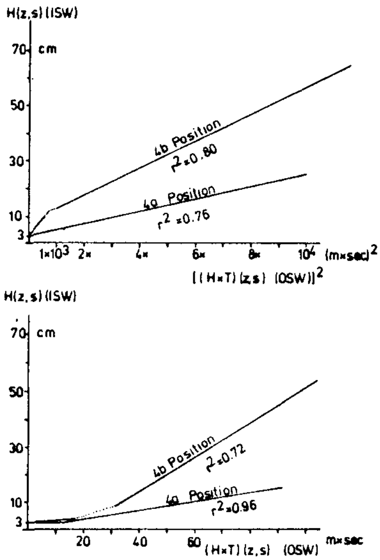

Fig. 4.- Correlation between H(z,s) (ILW) and the Product (H * T(z,s) (OSW)) : 4a) Lineal Fitting. 4b) Quadratic Fitting

amplification of the set-down proportional to H , instead to H^2 , in the inner harbour area. This amplification is due to an attenuation of the amplification factor caused by flow separation at the harbour entrance (Bowers, 1977).

The results calculated from the ILW, OLW, and SIWEH waves, obtained from the outside wave record, have also been correlated.

It was expected to obtain characteristic values of the number of waves in a group (Df/f(p)), taking into account the grouping factor GF. These values would allow to evaluate the transfer function Gnm between the short waves and the long set-down wave. However, the authors were not able to find a good correlation between the parameters GF and (Df/f(p))

The comparison between the values of T(z)(SIWEH) or T(z)(OLW) with T(z) (OSW) has not given a high level of correlation. There seems to be a tendency to show increasing values towards the storm peak, and then decreasing slowly . The correlation between T(z) (OLW) and Tz(OSW) was found to be somehow better in the following way :

Tz(SIWEH) = 6.6. T(z,s) (OSW) ; R^2 = 0.42

This expression is close to the value of the parameter fp/Df = 5, as found in Sedivy (Sand, 1982 a).

However, a certain value was systematically found for Tc(SIWEH) covering the range of 40-70 seg, coincident with the second spectral peak interval.