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A COMBINED DEVELOPMENT SCHEME FOR COASTAL AREAS EXPOSED TO HIGH WAVES

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Abstract: Based on the international experience concerning the sea waves' energy harnessing, a coastal installation, consisting of a concrete ramp for the waves run-up and subsequent water mass overflow towards an artificial reservoir, is considered, as an efficient and robust wave energy collecting device. Its preliminary design is based on the wave climate. The mechanical energy of the waves is transformed to electricity, via a system of low head turbines and a submarine outfall. In order to increase the efficiency of the scheme and to extend its scope, contributing in parallel to the socioeconomic upgrading of a coastal zone, too much exposed to sea waves to attract tourism, a scheme is proposed, comprising the use of the collecting reservoirs as recreational and fish farming coastal lagoons. The feasibility of the scheme depends on the coastal morphology, the geotechnical features of the coast and the optimal physical planning of the lagoon. A case study referring to the west coast of the island of Crete stems the study. The overall scale characteristics of the proposed scheme are: Wave run up installation length 150m, reservoirs extent 600000 m2 (depth 2-3m), mean annual electric power production 200 KW.

Key words: Wave- energy, coastal- zone- management

1 Introduction

The international experience on the sea waves energy exploitation, has documented that the wave power density, in order to be feasibly exploitable, has to exceed a mean annual value of the order of 10 KW/m and that the wave -energy- harnessing -devices have to withstand the extreme conditions of the area.

In Greece a few places are receiving such wave energy-flux, most of them around the island of Crete [1,2]. In those areas the multiple (combined) use of the energetic coastal water masses, make the project more feasible and socio-economically attractive.

Such a wave energy exploitation and coastal development scheme is presented in the following study, in a preliminary way, based on realistic wave and coastal data referring to the west coast of Crete.

It is anticipated that the realization of the project will offer a serious thrust to the socio-economic development of the area in an innovative way.

2 The principles

Among the dozens of wave energy harnessing-devices tested during the last 30 years, the only ones that survived and are considered at industrial scale, are the ones that are simple, robust, not comprising vulnerable mechanical components and ready to withstand the extreme destructive sea conditions rarely appearing in the area.

Such an offshore device is the Danish WAVEDRAGON, [4] consisting of an anchored floating reservoir, with a side ramp directed to the incoming waves. The running-up water-waves masses, fill the low depth reservoir, which is evacuated vertically to the sea, via a low head electricity - generating device. The vessel automatically becomes a submarine, in case of very bad weather. This is an offshore version of a similar coastal device consisting of coastal slopes, guiding water wave masses to an inshore reservoir, evacuated to the sea via a low head turbine and a submarine outfall.

That is a totally safe device, as only its robust structural concrete component is exposed to the waves, and the rest is well protected inshore. The position of the concrete slope(s), for waves over-spilling and discharging water inshore, is

crucial for the efficiency of the method, and a coastal promontory (a cape) with considerable water depths before it, is a preferred location, to increase wave energy due to possible refraction, with some wave breaking.
The water- collecting reservoir, in our case, is not only a means for water flow routing, but also an inland recreational facility (an artificial small size lagoon) for swimming, water sports and game fishing. The use of the basin, also, for extensive "natural" fish farming, is important, without the negative environmental effects of intensive fish farming, depending on the rate of renewal of the water in the reservoir.
The water level, in the reservoir, is of the order of 3 m above MSL, and a number of Low Head Turbines (LHT) can return, controllably, the collected-by-over-spilling water, to the sea via a submarine outfall crossing the breakers zone.
From the physio-graphic point of view, a small cape and a low coastal area, of approx. 100 hectares, are required. The limited permeability of the soil is crucial in reducing the "pond" formation cost.
The project can transform an isolated, abandoned, coastal area, due to high attacking waves, self sufficient in terms of energy and very attractive for marine recreation and fish farming, in a protected environment.

3 The site conditions

The coast of West Crete is exposed to the western winds of the East Mediterranean sea, with long, wave generation, fetches. The wave climate is estimated using the wind statistics and internationally established theoretical methods. The quantitative estimations retain their preliminary nature, because important information, like the wind and waves episodes duration, is conjectured.
The wind statistics are taken from an islandic meteorological station, exposed to the aforementioned winds, similarly to the coast of Crete.
The wind frequency- intensity (only moderate, strong and gale winds are considered) statistics are included in the Table 1.
The effective fetches for the prevailing SW, W and NW winds are respectively 750 km, 750 km and 580 km. The corresponding necessary wind durations are considered non realistic and the effective fetches are re-estimated on the basis of durations 20 hrs for the strong winds and 8 hrs for gale winds. The new vales are respectively 500 km and 150 km.

Table 1: Wind, mean annual frequency (%), intensity (mean speed) statistics.

	SW	W	NW
Moderate (7m/s)	6.46	8.84	6.63
Strong (15m/s)	1.94	2.35	1.56
Gale (22m/s)	0.36	0.23	0.16
Total frequency	8.76	11.42	8.35

The estimated significant wave height (Hs) and mean periods are tabulated.
The wave characteristics corresponding to the above (see Table 1) winds (Hs, Tmean) are included in the Table 2.

Table 2: Wave characteristics corresponding to the winds (see Table 1) (Hs-m, Tmean-sec).

	NW-SW	W
Moderate	2.8 / 7.5	3.5 / 8.0
Strong	7.0 / 10.0	7.0 / 10.0
Gale	7.7 / 9.0	7.7 / 9.0

The table suggests two main wave groups, the waves 3.0m/7.0sec and the waves 7.0m/10.0sec. Those two categories are used for the following preliminary design of the scheme. The first group, referring to the moderate winds has mean annual frequency 22%, while the second, referring to strong and gale winds, has mean annual frequency 6.6%.
Those values refer to the open sea, but the superposition of refraction and shoaling, under the assumption of minimal breaking (water depth before the wave harnessing device approx. 4m), permit the use of values of Hs (significant wave height) in front of the wave run-up slopes 2.5m and 4.0m respectively.
It is known that the waves have the ability to run-up on slopes 1/1 to 3/1 at heights 1.5 to 2 times their height. The most important design decision is the selection of the level of the overspill weir, in order to achieve the optimal mechanical wave energy exploitation.
At this stage, it is proposed to construct an overspill weir at a level, 3m above MSL on a cape. The weir has the form of a low fortification, a semicircular shape to collect waves coming from SW, W and NW and a length of 150 to 200m.

The over-spilling water discharge per m length of the weir is estimated by a modern, well- tested formula [3] for surging waves.

(1) $q= 0.2 \sqrt{(9.81\ Hs)^3}\ \exp(-2.6\ R/Hs)$

where, q (m2/s) is the specific discharge, R (m) is the level of the weir above MSL and Hs (m) is the significant wave height. Two values are considered 2m and 3.5m with mean annual frequencies 22% and 6.6% respectively.

4 Preliminary design issues

The project is located in the area of the municipality of Inahorion, at the SW of Crete, some kilometers north of Elafonissos a famous isolated swimming beach, close to the villages of Stomio and Elos.

The candidate locations are two low capes, protruding in the sea, coupled with a low land behind them, with altitude less than 3m above MSL, of rocky nature and of surface exceeding the required 100 he.

The far and near field illustrations of the locations are given in Fig 1, and Fig.2.

Figure 1: General view of the west Crete.

Figure 2: Possible locations in the area of the bay of Stomio.

The effective weir length at level +3m is considered equal to 150m.

Assuming wave episodes of 20hrs and 8 hrs respectively for the moderate and strong and gale winds, the volumes collected in the reservoir for each class of weather and waves are respectively, 1200000m3 for 2.5m waves and 3000000 m3 for 4m waves.

A reservoir of capacity of the order of 1200000m3 will be filled at level +3m above MSL 170 times under the above waves' conditions. The annually collected mechanical energy from the waves episodes is of the order of 1700 MWh.

The anticipated electric energy to be produced, assuming efficiency 80%, is of the order of 1400 MWh. This energy can be produced via two LHT installed at the outlet of the reservoir. The turbine characteristics are: installed power 200 KW at a pressure head of 3m.

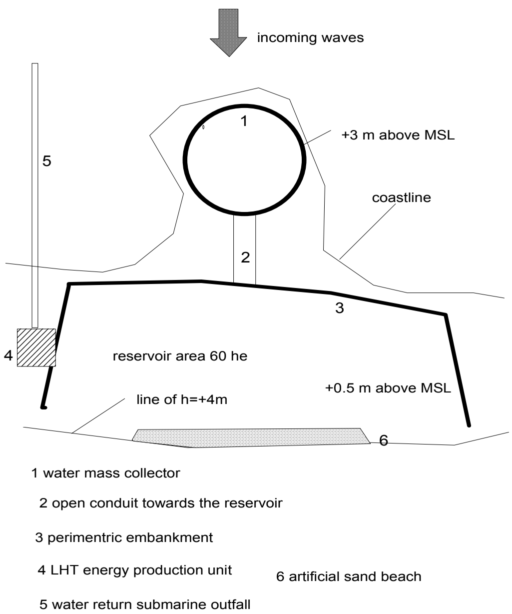
The corresponding water discharge, assuming a pressure head 3m is 16m3/sec.

At this design stage we assume that the reservoir has to contain the whole water volume from a typical wave episode, so for an average depth of 2.5m and a storable volume of 1200000m3, a surface of 500000m2 (50 he) is a required area.

The water collected to the reservoir will finally outflow to the sea (beyond the breaking depth of 5m).

An out of scale line diagram presenting the concrete weir-wall and the whole scheme is given in Fig.3.

Figure 3: Out of scale diagram of the development scheme.



The mean annual renewal frequency of the water in the reservoir is 28.6%, a percentage adequate to maintain good water quality and serve as a recreational of fish farming pond.
The bottom of this reservoir, have to be either lined or sealed in order not to have water leakage towards the lower ground strata.
A leveling of the area behind the wave harnessing cape at a level of +0.5 above MSL is anticipated to produce earth-rock masses of the order of 500000m3. This material will be used to construct the perimetric embankment to the reservoir. Of course, the leakage insulation problems, either through the bed or through the embankment have to be resolved via sealings and linings by geo-membranes. The use of a quantity of 100000m2 of geo-membranes is grossly estimated.
The return of the water to the sea will be achieved via a submarine outfall capable to discharge the maximum required quantity i.e. 16 m3/sec.

5 Gross feasibility analysis

Although the exact construction cost is a matter of detailed design and computations, a preliminary analysis shows that it is synthesized of:

1. The construction of the weir wall of 3m. Estimated cost 300000 €.
2. The moving of 500000m3 of earth and forming the embankment. Estimated cost 700000 €.
3. The construction of the open and the closed conduits of the water to the LHT and to the sea. Estimated cost 300000 €.
4. The linings and sealings of the reservoir bed and slopes. Estimated cost 400000 €.
5. The electric power devices (LHTs, electric current processing and connecting to the network). Estimated cost 1000000 €.
6. With unforeseen expenses of 15% the total cost is of the order of 3100000 €.

The income from the energy produced annually is of the order of 400000 €. The income from the fish farming and other maritime recreation is of the same order, 300000 €.
Assuming net gains of the order of 65% i.e. 450000 €, it can be documented that the project is feasible as the investment loan of 3100000 € can be paid back in 10 years.

6 Conclusions

An innovative scheme for the combined waves' energy exploitation for alternative energy production and secondary socio-economic development of an isolated deprived coastal zone of Greece is presented and documented at preliminary level.
The combination of the oceanographic conditions, the coastal morphology and the acceptable by the local society entrepreneurial uses, can lead to a scheme that apart from the direct feasibility has considerable added value can support the local society multiply and serve as a pilot for other European regions with similar conditions.

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