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Determination of Location of Floating Installations in the Shelf Zone

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Abstract. The article presents the results of using the graph analytical method for determining the most optimal locations for large-scale floating installations of photobioreactors (PBRs) for algae cultivation in the offshore zone of the sea in extreme weather conditions. For the region of the Black Sea experimental training ground, areas with the minimum energy of storm impact on floating installations were established. It is shown that in these areas where wave convergence occurs, refraction does not affect the height of the waves and the destructive effect on floating PBRs. The calculation results, which received satisfactory confirmation in the observations during the annual experimental tests, can be used in the design of areas for the placement of floating photobioreactors or other floating installations.

1. Introduction

In the interaction of winds in cyclones with the water surface, an important role is played by the heterogeneity of oceanological fields located on the path of their movement [1]. Floating platforms used to accommodate photovoltaic panels and systems of algal bio converters of solar energy [2–5] are capable of overlapping water areas with a noticeable area comparable to the active zone of extratropical cyclones. Marine-type floating energy systems that convert solar energy into algal biomass are currently widely used in areas with high solar activity and storm activity [4]. Microalgae ensure the biological conversion of solar energy in floating photobioreactors (PBRs) as a result of photosynthesis [6]. The tested experimental photobioreactors (PBRs) were large area floating systems with limited movement. They are quite flexible structures capable of tracking a storm wave and pre-hurricane wind loads [2]. Made of a durable, elastic material with positive buoyancy, they consist of a more significant number of cells with sides, which are connected on a general basis. The floating PBRs contain seawater with microalgae and nutrients. Sea wave intensity has a twofold role in increasing the efficiency of photosynthesis and growing biomass.

On the one hand, these should be small-amplitude wave motions that mix photosynthetic agents (microalgae). On the other hand, as a result of the interaction of waves with photobioreactors, the nutrient medium with algae and the structure of the energy plantation itself must be reliably protected from destructive wave effects. In this regard, there is a need to consider the issue of choosing the optimal location for sea-based energy plantations to ensure a relatively trouble-free and long-term



existence in the regimes most conducive to the implementation of active photosynthesis of solar energy.

2. An object of study and methods

To analyze the places of the optimal distribution of energy plantations, the area of the Black Sea marine range near the village of Katsiveli (Republic of Crimea) was selected. The geographical coordinates of the city at the location of the oceanographic platform (OP) are 44 ° 23'35.0 "N 33 ° 59'03.9" E [7]. The study used data of long-term observations of hydrophysical and meteorological parameters at this testing ground, necessary for solving the problem posed in work, which was published in 2012 [8].

The coast in the area of the experimental marine range is boulder-block. Bathymetry data in the field of the experimental test site are presented in the Navionics database [9]. In the coastal zone, there are elevations of underwater rocks above the sea surface, a significant number of blocks and rocks are hidden underwater, the slopes of the bottom go from 0.12 - 0.07%; at depths of more than 20 meters to a relatively gentler bottom with slopes of 0.05 - 0.04% in the coastal zone. In the beach area in the bay, slopes decrease to 0.03%. The monthly average wind speed, according to the coast station, is about 3.4 m/s, and maximum wind speeds reach 25 m/s [8]. Following the synoptic situation over the adjacent territory and the direction of the coastline extension, Sea wave direction is characterized by the clearly expressed predominance of E and SW waves (compass) point. According to meteorological observations carried out on the scientific Oceanographic platform, the average annual distribution of waves in the direction of predominance of E is 50% and SW-20%, respectively [7].

The analysis of storm situations shows that in the summer period, the maximum wave heights $h_{5\%} = 2-3$ m are also observed during in the east and southwest rhombuses. With an extreme recorded storm for the period 1959-1964, wave height of $h_{5\%} = 4.0$ m was found with an average period of 10 seconds. Storms with an average period of 7 seconds and a wave height of more than 2 m occur on average every 3-5 years.

The coastal zones of the seas are characterized, as a rule, by complex and heterogeneous conditions of the sloping topography. The hydrodynamic situation in such a situation is determined by wave refraction. In some cases, storm waves are subject to refraction due to the presence of significant depressions or ridges on the underwater slope. The consequences of wave refraction in hurricane winds are often catastrophic [10].

Refraction of sea waves, which manifests itself in the curvature and divergence or convergence of wave rays, leads to a redistribution of wave energy flows of the open sea in the coastal zone. In accordance with the requirement of placing photo blocks in the coastal area, it is necessary to take into account the energy impact of waves on the structure, and, accordingly, minimize this impact. One of the criteria when developing photo block layouts is: determining the distribution of divergent storm waves divergence zones over a selected area. A quantitative assessment of the influence of the refraction process on the height of waves in the photo blocks of a floating plantation is reduced to determining the refraction coefficients [11].

The work [12] contains the results of measurements of the frequency spectra of the Black Sea wind waves for various durations of wind action. The dimensionless values of the growth rate of the spectral components of the waves are presented, which show good agreement with the observations for the long-wave parts of the waves. These data were used for subsequent analysis.

An analytical expression of calculating the angle α between the wave line and any isobathic line T, obtained by V.V. Shuleikin [13], based on Snell's equation, was used to determine the distribution over the selected region of the divergence zones of waves of storm-hazardous rhombas:

$$\sin \alpha_H = \frac{H_n (H_{n-1} + 0,05T^2)}{H_{n-1} (H_n + 0,05T^2)} \sin \alpha_{n-1}$$

where H_n, H_{n-1} are the depths on the isobaths, for which the calculation is carried out,

α_n, α_{n-1} are the angles between the wave direction beam and the normal to the corresponding isobath.

The spectral method was widely developed in solving wave problems in the works of Yu.M. Krylov [14]. V.V. Efimov establishes the relationship between the energy spectrum of wave and altitude [12]. This method is mainly used for tasks on a significant spatial scale and without taking into account diffraction and adaptation to coastal waters. For algal plantations located in the coastal zone of the sea, it is not the spectral composition of energy that is of interest, but the choice of location, taking into account the refraction of waves, determined based on the bottom landscape [15].

Therefore, it is advisable to perform wave refraction estimates under real conditions in the coastal zone, specifying the orography of the relief of the underwater slope. To implement this, when constructing refraction plans, we chose the graph analytical method as the most suitable option for our calculations.

3. Results and discussion

To identify the divergence zones of waves of storm-hazardous rumbas, diagrams were developed for the refraction of waves E and SW (compass) point with an average period of 8 s and the average wavelength at the approach to the transformation zone of 100 m. For the construction, we used the coastal zone diagram with the horizontal bottom relief section through 10 m. The wave transformation of the calculated length begins at a depth of 6.5 m. However, the most significant effect of wave refraction is noted from a depth of 40 m. Orthogonal construction was carried out by successive iterations of the wave train curvature depending on the angle of direction to each isobath line.

An analysis of refraction plans allowed us to identify the four most discernable zones of storm wave divergence, in East waves (compass) point (zones I-IV in Figure 1, (a)) and 3 zones of separation for extreme wave direction SW (compass) point (zones V-VII in Figure 1, (b)). The refraction coefficients of the waves from the isobath of 40 m to the isobath of 10 m (Tab. 1) were determined as $R = \sqrt{\frac{L_{40}}{L_{10}}}$ where L_{40}, L_{10} - are the distances between the wave rays at depths of 10 and 40 meters, respectively.

Table 1. Values of the coefficients of refraction of waves in the zones of divergence

Sequence number of zone:	Distance between the wave rays of the divergence zones on:		$R = \sqrt{\frac{L_{40}}{L_{10}}}$
	L_{10} , m	L_{40} , m	
Sea wave of E (compass) point			
I	80	130	0,78
II	40	80	0,71
III	40	110	0,60
IV	70	120	0,76
Sea wave of SW (compass) point			
V	100	220	0,67
VI	20	80	0,50
VII	50	210	0,49

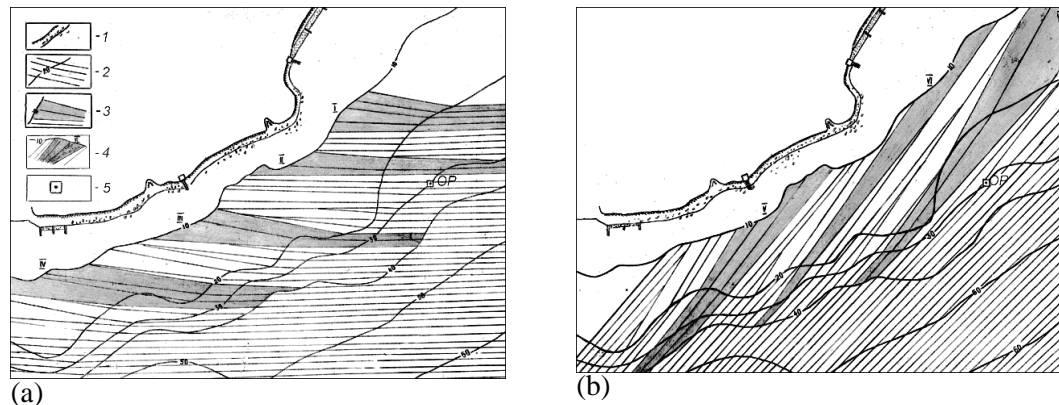


Figure 1. The refraction diagrams of East waves (a) and SW waves (b). Symbols on the chart: 1 - coastline, 2 - isobaths and wave rays, 3 - wave divergence zones of E (compass) point, 4 - wave divergence zones of SW (compass) point, 5 - oceanographic scientific platform (OP).

By superimposing wave refraction diagrams of South by SW and E (compass) point, regions representing zones of divergence of wave rays from storm waves in both cases were identified (Figure 2, (a)). The area at the intersection of divergence zones II and VI (Figure 2, (a)) was chosen as the optimal place for setting the floating installation of PBR on the territory of the marine range. The values of the coefficients of refraction of storm wave E and SW (compass) point at the point of setting were 0.72 and 0.53, respectively. Figure 2, (b) shows the choice of the optimal location for the installation of PBR concerning geographical coordinates (44 ° 23'39.1 "N 33 ° 58'48.7" E) on a satellite map of the area of the marine range on the Black Sea near the village of Katsiveli.

When developing the map, bathymetry data were adapted using Navionics GIS [9]. In zone III, which is supposed a floating plantation, the reduction in wave heights due to refraction, without taking into account the processes of wave transformation, should be 40%. In contrast, the difference in the degree of the energy impact of waves between the divergence zones will be an order of magnitude higher.

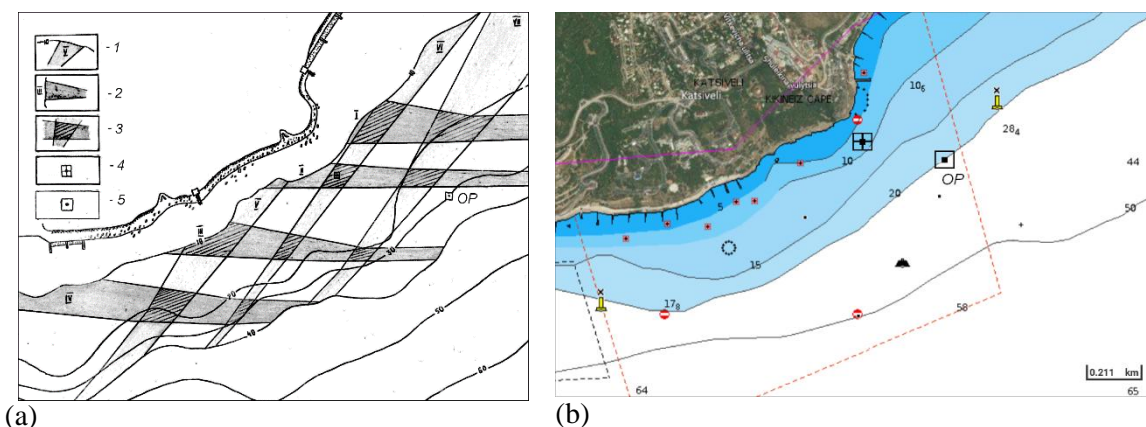


Figure 2. Selection of the optimal location for the installation of floating PBRs: (a) an analysis plan of overlapping refraction diagrams of SW and E waves, (b) concerning geographic coordinates on a satellite map of the area of the marine range on the Black Sea near the village of Katsiveli. Symbols in the chart: 1 - zones of divergence of waves E (compass) point, 2 - zones of divergence of waves SW (compass) point, 3 - the area of overlapping zones of divergence E and SW (compass) point, 4 - optimal location for the installation of floating photobioreactors, 5 - oceanographic scientific platform (OP).

4. Conclusion

Observations on the chosen point of optimal placement of the floating photobioreactors installation during an East storm of force 5 showed visual decreasing in wave heights in this area by about 30% in comparison with adjacent sections along the coast. A year monitoring of a floating plantation located on the coastal shelf place selected according to the calculations showed a stable operation and minor damage to the marginal (enclosing) walls of the farm. The storm impacts on structural elements in the placement zone turned out to be 80% less damaging in terms of surface damage of photo blocks compared to other areas under which photo blocks partially fell, where refraction had a significant effect on the height of the waves.

A similar construction of refraction plans can be done not only for the prevailing storm waves but also for other directions of the wave spectrum. The results were recommended for practical application in the design of marine-based «Biosolar» energy plantations [16, 17].

It should be noted that this method used to take into account the hydrodynamic situation when substantiating the location of floating installations of photobioreactors is based only on estimates of redistribution of storm energy caused by wave refraction due to inhomogeneities in the relief of underwater coastal slope. A complete account of the storm situation involves the study of the influence of surface currents and spectral characteristics of the waves.

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