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Study Conversion of Sea Wave Energy to Electrical Energy (Case Study: The Waves of the Caspian Sea)

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Abstract: In this study has been evaluated the wave energy resources along the Caspian Sea. The results of the analyses show that the wave energy come, from considerable wave energy resources are in the between South and middle basins of Caspian Sea. The main conclusion coming from the present research would be that the Caspian Sea and especially its Southern part which is shallow water, represents an adequate environment for an effective extraction of the wave energy. In this investigation, Caspian Sea has been considered as stratified and Boussinesq approximation has been considered. In equations governing the movement, cohesion and compressibility have been neglected. In the field studies, investigation of density profiles indicate signs of stratified structure which so far has been attributed to dual distribution convection phenomenon but by considering density ratio profile and values of density ratio which are mostly negative numbers, the factor causing stratified structure of Caspian Sea can be attributed to existence of internal waves. Density field in these two basins indicate that the middle basin has higher average density compared to the South basin this fact can cause creation of a gravity exchange flow. This exchange flow causes creation of internal waves in this sea that can have a modal structure towards vertical direction. In theoretical studies, the two middle and South basins of Caspian Sea are networked in two dimension x-z systems vertical and horizontal velocity profiles obtained from solution of these equations and also density profile obtained indicate that as a result of passage of gravity flow between the two basins, density in various points of the two basins change. So that, by placing the machine in the path of the waves in the Apsheron point is produced electrical energy. Therefore, in transfer and energy conversion, identification of the created strata is of a high importance.

Key words: Waves, internal waves, energy, Caspian Sea, shallow water

INTRODUCTION

According to UNESCO data CTD, Observations indicate existence of stratified structure in seas; so that the way of creation of stratified structure has always been a question. Different mechanisms such as dual distribution, internal waves and turbulent mixing have been proposed for creation of them (Fedrov, 2013). Ruddick (1992) believes that existence of stratified structure depends on dual distribution (Ruddick, 1992) but in the Caspian Sea the conditions of creation of dual distribution are less observed. Hence, existence of internal waves should cause creation of stratified structure. Therefore, mechanisms of internal waves are more acceptable for creation of a stratified structure. Existence of internal waves in stratified environments such as sea is very common. These waves have a more effective role in transferring the momentum in sea (Griffiths and Bidokhti, 2008; Gill, 1982).

Normal modes of these waves cause creation of shear layers which have also been observed in experimental mediums (Bidokhti and Shekarbaghani, 2011). The stratified structure related to normal modes of these waves can be important in vertical and horizontal transfer in marine environments or diffusion of sound waves which are usually used for searching in seas.

Wong *et al*. (2001) indicated that in closed environments, flows due to plumes that move in the bottom of the closed basin have caused internal waves that their phase velocity is towards down and their group velocity is towards up directions. Also this structure has caused creation of shear strata (5-7) which are effective in creation of stratified structure of physical quantities such as salinity and temperature (Bidokhti and Noroozi, 2004).

Vertical structure of physical properties such as salinity and temperature in lakes also indicate these strata. For instance, Boehrer (2000) by investigating vertical structure of salinity and temperature in Constance Lake indicated that regular strata are observed in them so that internal waves can be analyzed into modes that each can transfer independently, considering this fact that independent waves in lakes can be observed with higher probability. Therefore, the hypothesis that in lakes, all water motions end in internal waves is a reasonable hypothesis. Hence, he attributed the profile of flow velocity in Constance Lake to the velocity obtained from solving equations of internal waves and by proposing an analytic model of normal modes of internal waves, justified them (Wong *et al*., 2001).

Hogg *et al*. (2001) investigated role of internal waves in controlling stratified exchange flows between two closed marine basins by solving equations governing movement with numerical methods by determining Eigen value matrix. At first, created internal waves in an experimental simulation in order to create exchange flow in a reservoir including the two basins, then by examining waves in terms of location and time, calculated propagation velocity. After this operation, based on theory of hydraulic control in stratified current conservation, fluid velocity in defined and separate strata that their interaction occurs only in limited conditions was calculated and then compared with velocity of internal waves in the water column (Boehrer, 2000).

Baines and Turner (1969) indicated that gravity flows cause modal movements (together with internal waves) (Hogg *et al*., 2001). Hydrographical structure of Caspian Sea which is a closed lake is in such a way that can be considered in two middle and South basins. Existence of a mound between middle and South basins of Caspian Sea which is almost located beside The Apsheron Peninsula, causes that flow exchange between the two basins from top of the mound, cause creation of internal waves. Meaning that the gravity flow between the two basins especially on the bottom towards the South basin from top of the mound in the stratified area causes creation of such waves. On the other hand, modal structure of these waves should be effective in the way of flow exchange between these two basins.

Several studies have been conducted on coastal areas and waves caused by winds in the however, few studies have been conducted on marine physics of various parts of Caspian Sea. Therefore, it seems that the present study is a new approach in terms of issues of marine physics related to internal parts of the Caspian Sea especially in The Apsheron region which is a shallow region (Fig. 1).

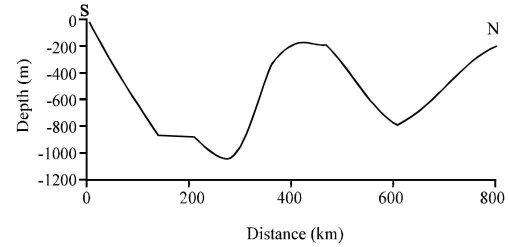

Fig. 1: Bottom topography of the Caspian Sea is indicated by distance from Southern Shore in Southern-Northern direction

Fig. 2: Map of the Caspian Sea, yellow shading indicates caspian drainage basin

Caspian Sea: The Caspian Sea is the largest inland body of water in the world and accounts for 40-44% of the totallacustrinewaters of the world (Fig. 2). The coastlines of the Caspian are shared by Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan. The Caspian is divided into three distinct physical regions: the Northern, Middle and Southern Caspian (Amirahmadi, 2000).The Northern Middle boundary is the Mangyshlak Threshold which runs through Chechen Island and Cape Tiub-Karagan. The Middle Southern boundary is the Apsheron Threshold, a sill of tectonic origin between the Eurasian continent and an oceanic remnant (Khain *et al*., 2007). That runs through Zhiloi Island and Cape Kuuli (Dumont *et al*., 2004).The Garabogazkol Bay is the saline Eastern inlet of the Caspian which is part of Turkmenistan and at times has been a lake in its own right due to the isthmus that cuts it off from the Caspian.

Differences between the three regions are dramatic. The Northern Caspian only includes the Caspian shelf and is very shallow; it accounts for <1% of the total water volume with an average depth of only 5-6 m. The sea noticeably drops off towards the Middle Caspian where the average depth is 190 meters. The Southern Caspian is the deepest with oceanic depths of over 1,000 m greatly exceeding the depth of other regional seas such as the Persian Gulf. The Middle and Southern Caspian account for 33 and 66% of the total water volume, respectively (Kostianoi and Kosarev, 2005). The Northern portion of the Caspian Sea typically freezes in the winter and in the coldest winters ice forms in the South as well.

Over 130 rivers provide inflow to the Caspian with the Volga Riverbeing the largest. A second affluent, the Ural River, flows in from the North and the Kura River flows into the sea from the West. In the past, the Amu Darya (Oxus) of Central Asia in the East often changed course to empty into the Caspian through a now-desiccated riverbed called the Uzboy River as did the Syr Darya farther North. The Caspian also has several small islands; they are primarily located in the North and have a collective land area of roughly 2,000 km^2. Adjacent to the North Caspian is the Caspian Depression, a low-lying region 27 m belowsea level. The Central Asians teppes stretch across the Northeast coast while the Caucasus Mountainshug the Western Shore. The biomesto both the North and East are characterized by cold, continental deserts. Conversely, the climate to the SouthWest and South are generally warm with uneven elevation due to a mix of highlands andmountain ranges; the drastic changes in climate alongside the Caspian have led to a great deal ofbiodiversityin the region.

The Caspian Sea has numerous islands throughout, all of them near the coasts; none in the deeper parts of the sea.

Field study: In this research, the obtained data by CTD measurements have been used for providing σ_t profile. Plan of the Caspian Sea and CTD measurement stations have been indicated in the first research tour of the International Atomic Energy Agency in Fig. 3. Field observations indicate σ_t profile of stratified structure of the Caspian Sea in Fig. 4. σ_t values in these waters are often negative and <1.

Waves: Internal waves in an area with density stratification can be obtained by analysis of the movement equations. In small movements, amplitude of pressure and density changes are as follows, respectively:

$$P = P(z) + P(x, y, z, t)$$
$$\rho = \rho(z) + \rho'(x, y, z, t)$$

Where:

P(Z) = Hydrostatic distribution of pressure in water column
P' = Represents fluctuations of pressure
ρ(z) = Vertical distribution of density field
ρ' = Also changes related to density field

Horizontal components of fluid's movement are as follows:

$$\rho(ut\text{-}fv) = \text{-}P'x \qquad \rho(vt\text{-}fu) = \text{-}P'y \tag{1}$$

and its vertical component is:

$$\rho(wt) = -P'_z - g\rho' \tag{2}$$

and the indexes are indicating the partial derivative (for example $Ut = \partial u / \partial t$). Also f = 2Ωsin Φ is the Coriolis parameter so that ϕ is the latitude and Ω is the angular velocity of the ground. Mass continuity equation for incompressible conditions is also as follows:

$$u_x + v_y + w_z = 0 \tag{3}$$

Also buoyancy conservation equation is:

$$0 = \frac{d\rho}{dz_t} + w\rho' \tag{4}$$

The equation indicates local changes of density due to vertical movements of the fluid in density field with vertical gradient. Due to existence of density difference between two points of the same height from two basins of the Caspian Sea and also density difference between two points in the same distance from coast and of different heights, value of N is variable. first the two basins in the Caspian Sea are networked and then the equation governing internal waves on points of the network are solved. K is wavenumber and L is wavelength. If wavelength is assumed to be one eighth of length of the region, by using relation of the wave number:

$$K = \frac{2\pi}{L} \tag{5}$$

wave number value for calculations obtained as equal to $2\pi\times10^{-5}m^{-1}$. N is the buoyancy frequency is wave frequency, C is wave propagation velocity, g' is the reduced gravity intensity and h is the height of water from sea level, then the following relations are obtained:

$$N^2 = \frac{\Delta\rho}{\Delta z}\times\frac{g}{\rho}$$

$$N^2_{j,(i-1)} = \frac{\rho_{j,(i-1)} - \rho_{j,i}}{\rho_{j,(i-1)} + \rho_{j,i}}\frac{2g}{\Delta z} \tag{6}$$

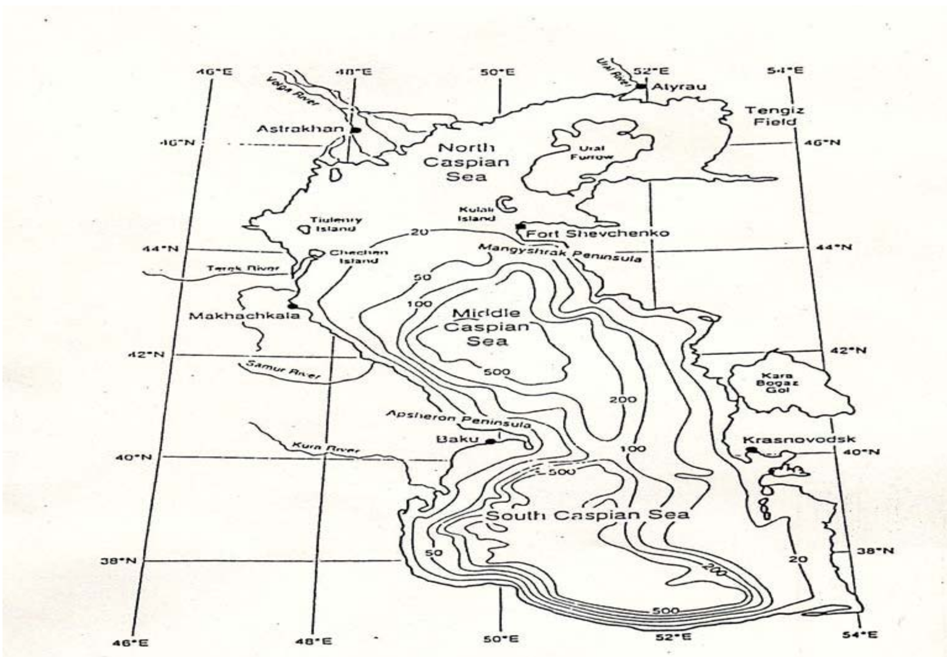

Fig. 3: Map of the caspian Sea and the stations of measurement

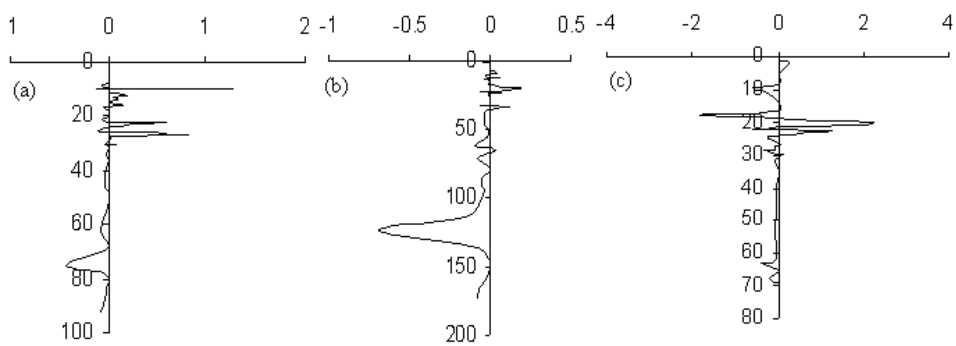

Fig. 4: Vertical profile of density ration in stations 4, 5 and 6: a) s4 density ration ; b) s5 density ration and c) s6 density ration

$$\omega = kc; \omega_{j(i-1)} = k(g'h)^{1/2}$$

$$\omega^2_{j,(i-1)} = k^2 \frac{\rho_{j,(i-1)} - \rho_{j,i}}{\rho_{j,(i-1)} + \rho_{j,i}} 2gh \quad (7)$$

$$\frac{N^2(j,i-1)}{\omega^2(j,i-1)} = \frac{1}{k^2 \Delta zh} \quad (8)$$

It is observed that for solving these equations, first j and i should be defined in the region being studied. Hence, networking method should be used. $W_{j,i}$ indicates vertical velocity in specific i and j which are situated in a specific point, $W_{j,i-1}$ indicates vertical velocity in a point with distance Δx from the coast and with height difference equal to Δz before the point (i,j) and indicates vertical velocity in a point with distance from the coast and height difference equal $2\Delta z$ to before the point (i,j).

Effect of internal waves on energy transfer: According to the observations from field studies (drawing density ratio profile), it was found that dual distribution convection is not often created in Caspian Sea and it doesn't seems that this convection has a main role in stratified structure in the Caspian Sea but also waves have a main role in these waters.

Field studies confirm existence of surface flows from North to South and also creation of flow from surface water of the middle basin and upwelling of this flow from depth. Transfer of this flow occurs together with water stratification and creation of internal waves. Also analytic studies confirm existence of such waves and water stratification and Fig. 5 indicates existence of vertical modes of internal waves in Caspian Sea.

This fact implies existence of internal waves which cause creation of stratified structure. Generally, in the Caspian Sea, normal modes of internal waves are produced with long wavelength by entrance of rivers in an environment with stratified layers and finally result in complete stratification of Caspian Sea, so that, within long period of time, the flow transfers from one stratum to another, movement of this flow causes excitation of the internal waves which propagate energy towards vertical direction. Internal waves, in environments with stable density stratification like Caspian Sea waters can transfer energy. Meaning that this flow, together with changes in velocity due to passage of various strata of water with different densities, reaches water surface and then the phenomenon of water rotation on surface of the sea can be observed. Sometimes when internal waves break, turbulence caused by this event, creates stratified structure (Baines and Turner, 1969). The main reason of creation of exchange flow between the two basins of the Caspian Sea is horizontal gradient of density, that in this phenomenon, internal waves are created and have effect on this exchange and sign of existence of such internal waves is stratified structure observed. The Stratified structure in Caspian Sea mainly exists in the part under the mixed stratum.

Existence of stratified structure also has effect on thermal distribution coefficient and cause transfer of heat in Caspian Sea waters and is also effective in extent of exchange of waters. Also existence of various water strata with different densities is effective in propagation of sound waves which is considered as mechanical waves, so that the more an stratum is denser, the more velocity of sound wave increases in that stratum. Hence, in various water strata, sound wave is also different and at the time of passage of sound from one stratum to another, failure phenomenon for sound waves occurs.

For the conversion of wave energy into electrical energy from a device is used as shown in Fig. 6.

Hydro energy: Hydro energy is available in many forms, potential energy from high heads of water retained in dams, kinetic energy from current flow in rivers and tidal barrages and kinetic energy also from the movement of waves on relatively static water masses. Many ingenious ways have been developed for harnessing this energy but most involve directing the water flow through a turbine to generate electricity (Fig. 7). water turbines, like steam turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different families of turbines have been developed to optimise performance for particular water supply conditions.

In general, the turbine converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft. Swiss mathematician Leonard Euler showed in 1754 that the torque on the shaft is equal to the change in angular momentum of the water flow as it is deflected by the turbine blades and the power generated is equal to the torque on the shaft multiplied by the rotational speed of the shaft (Fig. 8).

Note that this result does not depend on the turbine configuration or what happens inside the turbine. All that matters is the change in angular momentum of the fluid between the turbine's input and output.

Available power: The maximum power output from a turbine used in a run of Wave Sea is equal to the kinetic energy (½ mv^2) of the water impinging on the blades. Taking the efficiencyçof the turbine and its installation into account, the maximum output power P_{max} is given by:

$$P_{max} = \frac{1}{2}\eta\rho Q v^2 \tag{9}$$

where, v is the velocity of the water flow and Q is the volume of water flowing through the turbine per second. Qis given by:

$$Q = AV \tag{10}$$

where, A is the swept area of the turbine blades. Thus:

$$P_{max} = \frac{1}{2}\eta\rho A v^3 \tag{11}$$

Note that the power output is proportional to the cube of the velocity of the water. Thus, the power generated by 1 cm^3 of water flowing at 1 m sec^{-1} through a turbine with 100% efficiency will be 0.5 kW or slightly less taking into account the inefficacies in the system.

Hydroelectricity: Hydroelectricity is electricity produced from hydropower. In 2015 hydropower generated 16.6% of the world's total electricity and 70% of all renewable electricity and was expected to increase about 3.1% each year for the next 25 year.

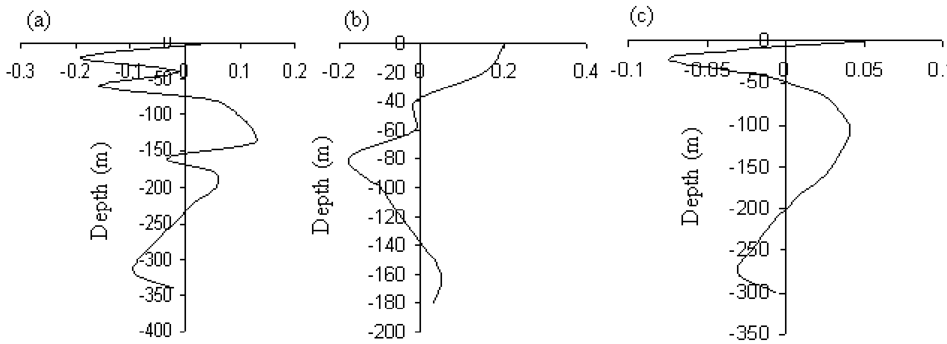

Fig. 5: Profiles of horizontal velocity calculated in stations 4, 5 and 6 (x distances are from Caspian Sea South coast S4 j = 6; S5 j = 7; S6 j = 8

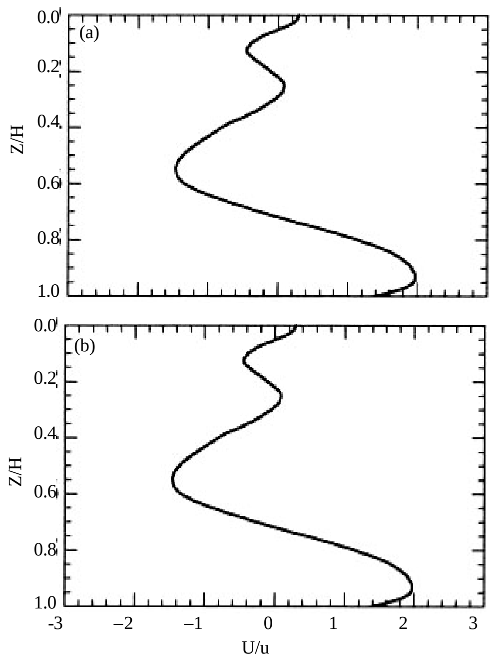

Fig. 6: Horizontal velocity made dimensionless by internal velocity of mixing obtained in two successive times created in the same stratified structure by a plume in a closed environment with density stratification.

Hydropower is produced in 150 countries with the Asia-Pacific region generating 33% of global hydropower in 2013. China is the largest hydroelectricity producer with 920 TWh of production in 2013, representing 16.9% of domestic electricity use.

The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. The hydro station consumes no water, unlike coal or gas plants. The average cost of electricity from a hydro station >10 mW is 3-5 US. Cents/kWh. With

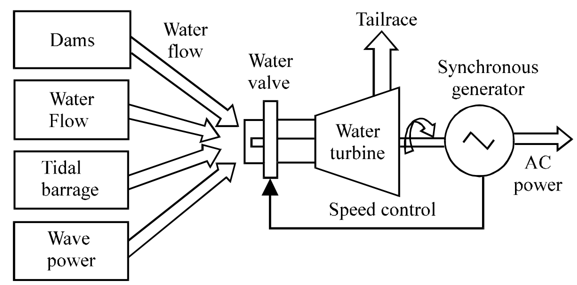

Fig. 7: A view of the hydro electric power generation

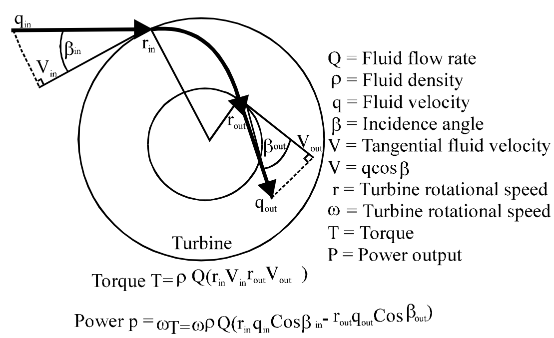

Fig. 8: Diagram of the turbine of euler

a dam and reservoir it is also a flexible source of electricity since the amount produced by the station can be changed up or down very quickly to adapt to changing energy demands. Once a hydroelectric complex is constructed, the project produces no direct waste and has a considerably lower output level ofgreenhouse gases than fossil fuelpowered energy plants.

CONCLUSION

These profiles indicate that due to passage of gravitational flow between the two basins, density in various points of the two basins change and since South and middle basins of Caspian Sea are related to each other through a mound (The Apsheron point), in the conducted studies it is observed that flow of the middle basin moves towards the South basin and overflows from top of the mound between the two basins, then from bottom of the mound, the flow returns towards the middle basin. And this fact is consistent with measurements conducted by UNESCO (1995). By placing the Hydro Electric Power Generation in the path of the waves in The Apsheron point is produced electrical energy.

Since for creation of dual distribution convection density ratio should be almost equal to 1 this phenomenon does not often occur in this sea, hence we cannot attribute the observed strata to this phenomenon. But the modal structure created from internal waves on the mound causes creation of shear strata observed. Hydro-electric power, using the potential energy of rivers, now supplies 17.5% of the world's electricity (99% in Norway, 57% in Canada, 55% in Switzerland, 40% in Sweden, 7% in USA). Apart from a few countries with an abundance of it, hydro capacity is normally applied to peak-load demand because it is so readily stopped and started. It is not a major option for the future in the developed countries because most major sites in these countries having potential for harnessing gravity in this way are either being exploited already or are unavailable for other reasons such as environmental considerations. growth to 2030 is expected mostly in China and Latin America. The created strata, in addition to distributing organic substance and also oxygen existing in Caspian Sea waters, causes energy transfer that by using energy convertor of waves in this place, electric energy is produced.

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