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PROSPECTS FOR THE USE OF MICROSEISMS, CAUSED BY STANDING WAVES OF WATER BODIES

The purpose of the research is to find possible ways to use microseisms, caused by standing waves in water bodies. According to the theory, standing waves arise when two traveling waves, moving towards each other collide. The first of them falls on an obstacle and the second one reflects from it. The conditions of excitation the waves and swinging of damped waves are presented. Evidence shows that the wave pressure at the antinodes at the boundaries of the water medium separation and the soil is proportional to the wave amplitude on the water. The possibility of using standing waves in seismic exploration is confirmed by the observation data of storm microseisms at remote stations. To increase the transmission range, it is advisable to use long-period microseisms, which provide low damping. One method to reduce the risk of an earthquake involves the initiation of weak seismicity by artificial sources in order to periodically relieve excess tectonic stress. One of the most powerful sources of lithospheric deformations is the natural oscillations of the liquid level in large water bodies. The study considers the idea of using the resonance effect of tidal-seiches vibrations to initiate weak seismicity. Artificial excitation of the seiche is achieved when controlling a water culvert. Transmission network supports multiplexing of communication channels with separation by physical nature and transmission media. When managing culverts, seiches oscillations are artificially swung with phase-shift oscillations. Phase shift of the exciting wave relative to the damping wave, in turn, causes variations in seiche periods, which leads to proportional variations in the periods of microseisms. This solution allows encoding messages by the durations of seiches and microseisms, with their subsequent transmission. Hydrological observations revealed the effect of the dependence of surface seiches periods on water depth. The solution of the inverse problem, with the measured seiches period, allows calculating the water body depth. Method of remote measurement has been proposed using the analysis of ground oscillations of seiches origin. Analysis of variations in the electromagnetic radiation of the geological environment has shown that they are determined by the mechanisms of energy conversion of these processes into the energy of the electromagnetic field. The study of these variations allows us to calculate the depth of the water body. Originality. Methods for using microseismic oscillations excited by standing waves are considered in detail. The methods of managing standing waves are presented: by regulating the depth of the reservoir; by regulating the period of the exciting wave; by regulating the phase of the exciting wave. The dependence of the amplitude of the resulting oscillation of standing waves on the phase of the exciting oscillation of the same period was investigated. Innovative developments protected by patents of Ukraine are presented, which imply the economic use of microseisms caused by standing waves of water bodies. It is noted that both the necessity and the possibility for using one or another method of performing a specific task are determined by internal and external objective conditions that exist at a certain time in a certain space.

Key words: damping of waves; exciting of waves; seiches; surf beat; swinging of waves.

Introduction

Short-period microseismic oscillations are widely used in seismic exploration.

The article discusses the possibility of using passive seismic techniques to study the deep structure of the region. Seismic noise, which has certain characteristics in the conditions of a specific region, is used as a probe signal in such methods [Lyaschuk et al., 2015].

The practical application of the microseismic waves with a frequency 2–4 Hz is possible for search and localization of hydrocarbon deposits, as well as the evaluation of the depth of occurrence of inhomogeneities, in particular oil and gas-bearing contours [Zatserkovny et al., 2016].

The results of inspection structures using microseisms reveal the weakest points in the structure of buildings. The presence of constant monitoring to track the slightest changes in the state of structures in order to take timely measures to localize the defect [Terent’ev et al., 2015]. In particular, microseisms with a frequency of 0.5–10 Hz are excited in the geological environment during the operation of electric machines. They are used to solve construction tasks based on the analysis of waves of various genesis and types (emission, man-made signals, surface waves) [Yegupov, 2018].

One of the most powerful sources of lithospheric deformations is the pressure of standing waves with the period of natural oscillations of the water basin, seiches and surf beat (for example, [Nasonkin et al., 2008; Nesterov, 1996]).

Their profile changes in time between nodes, and the amplitude of the level fluctuations changes along the wavelength, reaching a peak in the antinode, as it is shown in Fig. 1.

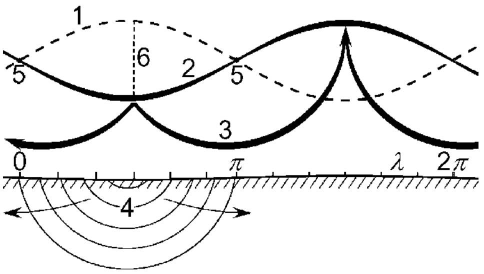

Fig. 1. Complex of phenomena arising from the action of standing water waves in the hydrosphere and Earth's crust

1, 2 – wave amplitude at times t=0, t=π; respectively; 3 – current direction immediately before the wave reaches the maximum (optimal) value ($t \to \pi$); 4 – microseisms at time $t \to \pi$; 5, 6 – nodes and antinodes of the wave, respectively (from [Anakhov, 2019], modified)

In many water bodies seiches operate during 30–50 % of the duration of the ice-free period. In Lake Baikal, they are almost continuous. Single-node fluctuations have the highest repeatability – 84 % of the duration of the ice-free period. In Lake Balkhash, seiches operate on average approximately 60 % of the time, and in some months of the ice-free period, the total time of their operation reaches 80 % [Sudolsky, 1991]. In general, the seiches fluctuations of the water mass are a normal state for any water body at every moment of its existence, and if they are not always noticeable, then this is only a consequence of small amplitudes of oscillation [Labzovsky, 1971].

The work of Sudolsky (1991) presents the results of observations of seiches fluctuations in the summer months of 1970 and 1971 in the central part of the largest reservoir in Ukraine, Kakhovsky.

It is reported that 12 Black Sea ports are affected by the surf beat: Tuapse, Sochi, Poti, Batumi, Samsun, Giresun, Burgas, Varna, Constanta, Illichivsk, Yalta, Feodosia and some Sevastopol bays [Balinets, 2007; Labzovsky, 1971].

In addition, during the period 1982–2006, 85 cases of surf beat were observed in the Chornomorsk seaport of Odesa region [Gavrilyuk & Berlinsky, 2019].

Standing waves cause fluctuations of the entire volume of the water mass, resembling a piston that performs reciprocating movements. The author has not received any reports on the use of long-period microseismic oscillations caused by the action of seiches and surf beat.

Purpose

The purpose of the research is to find possible ways for using microseisms caused by standing waves of water bodies.

Method

According to the theory (for example, [Rabinovich, 2014; Sudolsky, 1991]), standing waves arise when two traveling waves, moving towards each other, collide.The first of them falls on an obstacle $A_{incident} = A_0 \cos(kx - \omega t)$ and the second one reflects from it $A_{reflected} = A_0 \cos(kx + \omega t)$. As a result, a wave is formed as follows.

$$A_{sw} = A_{incident} + A_{reflected} = 2A_0 \cos(kx)\cos(\omega t), \quad (1)$$

where $A_{incident}$, $A_{reflected}$, A_{sw}, A_0 are the amplitudes of the incident, reflected, standing waves and the initial wave amplitude, respectively; k is the wave number ($k = 2\pi / \lambda$); λ is wavelength; ω is the cyclic frequency $\omega = 2\pi / T$); T is the wave period; x, t are the variables for length and time.

According to [Rabinovich, 2014], standing waves are excited at the resonance of an exciting external (for example, incident on an obstacle with amplitude A_{inc}) wave with a period of T_{exc}, and an excited standing wave with a period of T_{sw}.

The article [Dogan et al., 2021] considers the excitation model of a long-period standing wave in the case of coincidence of the propagation speeds of the exciting V_{exc} and excited V_{ph} waves.

Based on this, we can record the condition of excitation of standing waves in the following form:

$$(T_{exc} \to T_{sw}) \vee (V_{exc} \to V_{ph}), \quad (2)$$

where $\vee$ is the logical operation of disjunction.

The seiches wave period of the water body can be calculated by the formula [Rabinovich, 2014]:

$$T_{sw} = \lambda_{sw} / (nV_{ph}) = const, \; n = 1, 2, 3, \ldots, \quad (3)$$

where λ_{sw} is the length of the standing wave of the water body, which is determined by its morphometric characteristics ($\lambda = 2L/m$); L the length of water body L (for longitudinal seiches); m – oscillation mode, $m = 1, 2, 3, \ldots$; V_{ph} is the phase velocity of waves ($V_{ph} = \sqrt{g\overline{D}}$); g is gravitational acceleration $g \approx 9.8$ m/s^2); D is water depth.

Standing waves are subject to damping. Considering this, let us rewrite the equation (1) as follows [Sudolsky, 1991; Rabinovich, 2014]:

$$\begin{aligned} A_{sw} &= A_{inc} + A_{ref} = \\ &= 2A_0 \cos(kx)\cos(\omega t)\exp(-2\delta\omega t) \end{aligned}, \quad (4)$$

where $\exp(-2\delta\omega t)$ is the principle of oscillation damping; δ is the logarithmic decrement.

Seiches oscillations are supported by swinging. Let us describe the swinging wave as

$$A_{exc} = A_0 \cos(\omega t + \varphi),\ 0 \le \varphi \le 2\pi, \quad (5)$$

where φ is the phase.

Then, when the seiches and one swinging wave with a similar oscillation period is added, the resulting wave A_{res} of the following form appears:

$$\begin{aligned} A_{res} &= A_{sw} + A_{exc} = \\ &= 2A_0 \cos(kx)\cos(\omega t) + \cos(\omega t + \varphi) \end{aligned} \quad (6)$$

The wave pressure at the antinodes at the interfaces of the media (water and soil) is proportional to the wave amplitude on the water. It can be calculated by the formula [Evers, 2008]:

$$P = 2\rho A^2\omega^2 \cos(2\omega t), \quad (7)$$

where ρ is water density ($\rho \approx 1.000$ kg/m^3).

The significant energy potential of the seiche waves and currents, predictability of their values and location of maxima, availability, the presence of such secondary impacts as microseisms in the lithosphere, determine the prospects for their economic use. Complex of phenomena arising from the action of seiches in the hydrosphere and Earth's crust is shown in Fig. 1.

Ways for use microseisms

Seismic exploration

The possibility for use of standing waves in seismic exploration is confirmed by observation data of long-period storm microseisms at significantly remote stations [Tabulevich, 1986].

According to the decision protected by Patent of Ukraine 87564, to increase the transmission range, it is advisable to use long-period microseisms, which provide low damping (see formula (4)) [Specialized DB].

In addition to the traditional way of using microseisms for seismic exploration, "exotic" applications of standing waves are proposed.

Relief of tectonic stress in the Earth's crust

One method to reduce the risk of an earthquake involves the initiation of weak seismicity by artificial sources in order to relieve excess tectonic stress. The impact of microseismic oscillations on the geological environment can be that their action ensures the directed evolution of deformation processes in the Earth's crust. Thus, rocking movements lead to creep movements and low-frequency "silent earthquakes" along seismogenic faults [Strakhov & Savin, 2013; Ruzhich et al., 2021].

The possibility of new, or an increase in the existing seismic activity due to the creation of reservoirs was discovered last century. It involved the effect of earthquake excitation by filling reservoirs. The causes of earthquakes include, in particular, the action of such microseismogenic processes as water level variations and formation of storm microseismic zones [Gupta & Rastogi, 1975].

In the works [Nesterov, 1996; Chekhov et al., 1994] substantiate the assumption that natural oscillations of the liquid level in large water bodies is one of the most powerful sources of lithospheric deformations that precede earthquakes .

For example, a storm surge with a height of slightly more than 2 m in the southern part of the North Sea causes standing waves (see formula (2)), under the condition that the propagation speeds of the exciting and excited waves coincide. Standing waves, in turn, cause vertical displacements of 20–30 mm and an increase in gravity by 6–8 mgal in the coastal areas of Denmark, Germany, the Netherlands, and the east coast of England [Fratepietro et al., 2006].

According to Academician I. Kurchatov (1982), elements of the same period can be found in the hydrological life of any water basin. Obviously, these elements can always serve as an exciting force for the basin. So, the coincidence of the period of natural oscillations and external forces acquires special importance.

Let us write down the condition of excitation of the water mass ($T_{exc} \to T_{sw}$) in the form of resonance of an external tidal wave T_{exc} with a period close to the period of seiche oscillations T_{sw} [Rabinovich, 2004]:

$$A_S = \frac{1}{\left(1 - T_{sw}/T_{exc}\right)^2 + Q^{-2}\left(T_{sw}/T_{exc}\right)^2},$$

$$nT_S \approx T_T,\ n = (1; 2; \ldots; n) \cup \left(1; \frac{1}{2}; \ldots; \frac{1}{n}\right), \quad (8)$$

where Q is the quality factor, which is a measure of energy damping in the system, n is the coefficient.

The idea of using the resonance effect of tidal-seiches vibrations to initiate weak seismicity is protected by the Patent of Ukraine 83039. The seiche is artificially excited when controlling a water-passing (water-discharge or water-lifting) hydraulic structure. In this case, the period of the external wave T_{exc} determines the duration of the water inflow [Specialized DB].

Encoding and transmission of messages

The scheme of a full-fledged hybrid network of information transmission is a three-level hierarchical sequence of multiplexers, as shown in Fig. 2.

According to the scheme shown in Fig. 2, the hybrid information transmission network, in addition to frequency (i.e., spectral, wavelength division multiplexing) and time division multiplexing, supports multiplexing of communication channels with physical and media separation. Table 1 presents the matrix of their correspondence.

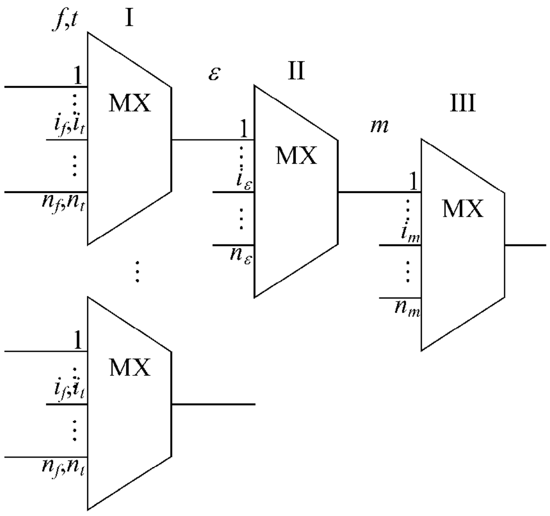

Fig. 2. Functional diagram of the transmitter of the hybrid information transmission network:

I is the level of channels multiplexing with the frequency-time division of signals; II is the level of channels multiplexing with the separation of signals by physical nature; III is the level of channels multiplexing with signal separation by transmission media (from [Anakhov et al., 2020], modified)

Table 1 provides generalized information on possible ways of transmitting information. Based on these data, it is possible to announce a geophysical (microseismic) method which is a new method of transmission. It is carried out in the following way. When managing culverts, seiches oscillations are artificially swung with phase-shift oscillations. The analysis of the oscillatory process showed that, firstly, seiches are prone to damping, and secondly, the amplitude of the oscillations is significantly affected by the phase of the swinging wave. Fig. 3 shows this dependence at a fixed instant of time $t = const$ in the antinode $x = const$, when swinging by a wave of similar amplitude with an arbitrary phase.

Table 1

Correlation matrix of the signals of different physical nature is used for information transmission via media [Anakhov et al., 2022a]

Physical nature of the signal	Transmission medium				
	Atmosphere	Space	Underwater	Underground	Artificial guides
Acoustic	+	-	+	+	+
Electromagnetic	+	+	+	+	+
Optical	+	+	+	-	+
Quantum	+	+	-	-	+
Neutrino	+	+	+	+	-

Phase shift of the exciting wave relative to the damping wave, in turn, causes variations in seiche periods, which leads to proportional variations in the periods of microseisms. This solution, protected by the Patent of Ukraine 127562, allows to encode messages with the durations of sessions and microseisms, with their subsequent transmission [Specialized].

Water depth measurement

The hydrological observations of Lake Sevan, Armenia, on the use of its water reserves for irrigation and energy purposes started in 1933. They revealed the effect of the dependence of surface seiches periods on water depth [Azernikova, 1975]. The effect is illustrated by the example of a closed rectangular pool with a horizontal bottom (see formula 3).

The solution of the inverse problem, with the measured seiches period, allows calculating the reservoir depth.

Cyclic changes in the level during seiches oscillations generate microseisms. On this basis, in addition to direct depth measurement, a remote measurement method is proposed. According to the solution protected by the Patent of Ukraine 90436, it uses the analysis of ground vibrations of seiches origin. This is advisable when measuring the depth of remote water bodies, information about which may be limited [Specialized].

Observations of the ripples on Lake Sevan (Armenia) [Azernikova, 1975] and the Aral Sea (Kazakhstan, Uzbekistan) [Berg, 1908] revealed the instability of the frequencies of the reference signal – seiches. This is negatively determined during measurements.

Table 2 lists the causes of variations in seiche periods that are not due to internal causes (by changes in the depth of the reservoir). The study of geophysical processes shows that the action and development of some phenomena always creates the preconditions for the emergence and development of others. In the late 1930s, A. Ivanov reported the discovery of a seismic effect of the 2nd kind, the essence of which is that the geological environment under the action of a seismic field generates an electromagnetic field [Ivanov, 1939]. Analysis of variations in the electromagnetic radiation of the geological environment has shown that they are determined by the mechanisms of energy conversion of these processes into the energy of the electromagnetic field [Anakhov et al. 2022b].

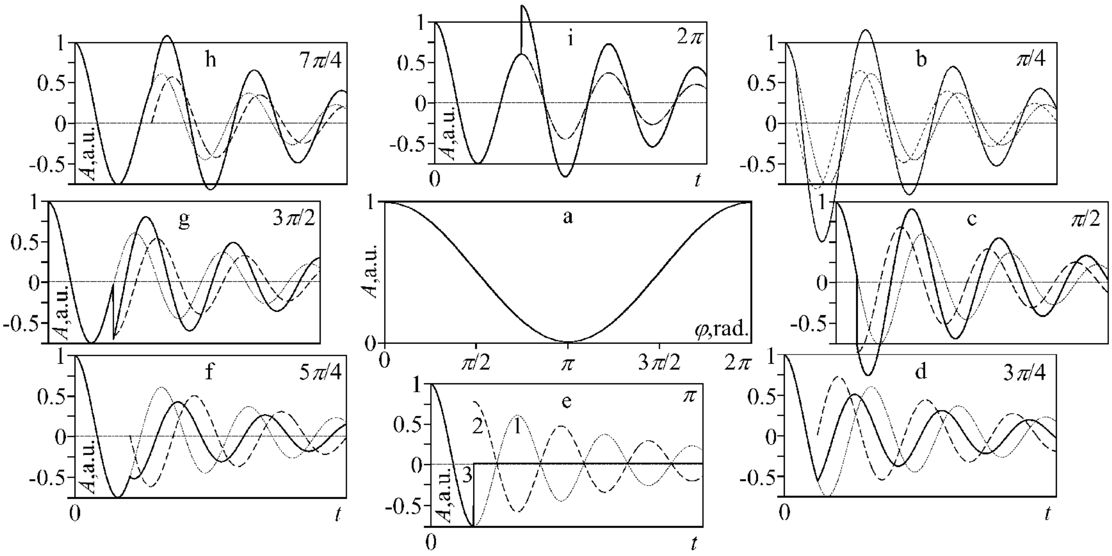

Fig. 3. Amplitude of the resulting oscillation of the seiches A_{res} during the swing by a wave with an arbitrary phase (0£j £1)

a – dependence of the amplitude of the resulting oscillation on the phase of the swinging oscillation in the antinode at a fixed time; b–i – dependences of the amplitude of the resulting oscillation on time when the damped seiche is swinging by a wave of the same period and amplitude with a phase shift p/4, p/2, 3p/4, p, 5p/4, 3p/2, 7p/4, 2p, respectively; 1, 2, 3 – damped, swinging and resulting oscillations, respectively

Table 2

External causes of variations of seiche periods [Anakhov P. & Anakhov S., 2016]

Reasons for variations	Explanation
1. Excitation by a wave with a period close to the seiche one	For the time interval, the actual excitation of the oscillations
2. Changes in the characteristic length of the profile along which oscillations are carried out, as a result of a change in the direction of the axis of oscillations	– by changing the direction of the barometric gradient or wind direction
	– when the outgoing wave passes around the amphidromic point (coincides with the seishes node) caused by the Earth's rotational motion
3. Simultaneous changes in the length and depth of the profile along which oscillations are carried out	– due to the leveling of the water surface during storm surge, inflows and outflows of the river, rain
	– when morphometric characteristics change (for example, as a result of a disaster, or during hydraulic construction)
4. Interference with seiches of the same or another period	Due to the phase modulation of damping seiches during their swinging

The study of these variations allows to calculate the depth of the water body.

Originality

The study conducted a detailed analysis of methods of using microseismic oscillations excited by standing waves. The methods of managing standing waves are presented by the following: regulating the depth of the reservoir; regulating the period of the exciting wave; regulating the phase of the exciting wave.

The dependence of the amplitude of the resulting oscillation of standing waves on the phase of the exciting oscillation of the same period was investigated.

Practical significance

Innovative developments protected by Ukrainian patents are presented, which imply the economic use of microseisms caused by standing waves of water bodies. A list of methods of using weak influences on the lithosphere and possible grounds for their use are presented in Table 3.

It should be noted that both the necessity and the possibility of using one or another method of performing a given specific task are determined by internal and external objective conditions that exist at a certain time in a certain space.

Table 3

Ways for use microseisms and possible grounds for their use

Method	Reason
Seismic exploration	Passive seismic exploration, in which a reference generator may not be used, given that standing waves of the water mass are a normal state of the water body
Relief of tectonic stress in the Earth's crust	The possibility of controlling microseisms by applying an exciting external wave
Water depth measurement	It is useful for remote measurement of the depth of remote water bodies, information about which may be limited
Encoding and transmission of messages	Let us estimate the transmission speed of a message encoded in the octal number system (see Fig. 3) using a wave with a period of 9 s. If one elementary signal of the code corresponds to a period of rocking oscillation (discrete signals with a phase shift φ from $\pi/4$ to $7\pi/4$), and the second signal corresponds to a pause with a duration in the oscillation period ($\varphi = 2\pi$), the transmission rate will be 7 characters / 18 s = 0.4 bit/s. For comparison, in 2012, a wireless neutrino communication session was demonstrated over a distance of 1,035 km, including through 240 m of rock. The data transfer rate was 0.1 bps [Stancil et al., 2012]

Conclusions

1. The study presented innovative developments protected by patents of Ukraine, which imply the economic use of microseisms caused by standing waves of reservoirs: seismic exploration; relief of tectonic stress in the Earth's crust; encoding and transmission of messages; water depth measurement.

2. The dependence of the amplitude of the resulting oscillation of standing waves on the phase of the exciting oscillation of the same period was investigated.

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Павло АНАХОВ

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ПЕРСПЕКТИВИ ВИКОРИСТАННЯ МІКРОСЕЙСМІВ, ВИКЛИКАНИХ СТОЯЧИМИ ХВИЛЯМИ ВОДОЙМ

Метою досліджень є пошук можливих способів використання спичинених стоячими хвилями водойм мікросейсмів. Відповідно до теорії стоячі хвилі виникають у разі зіткнення двох хвиль, що рухаються назустріч одна одній. Подано умови збудження хвиль і розгойдування хвил, які затухають. Наведено докази того, що тиск хвилі в пучності на межах поділу водного середовища і ґрунту пропорційний до амплітуди водяної хвилі. Можливість використання в сейсмічній розвідці стоячих хвиль підтверджується даними спостережень штормових мікросейсмів на віддалених станціях. Для збільшення дальності передавання доцільно застосувати мікросейсми з великим періодом, які забезпечують низьке затухання. Один зі способів зменшення небезпеки землетрусу передбачає ініціювання слабкої сейсмічності штучними джерелами з метою зняття надлишкового тектонічного напруження. Одним з найпотужніших джерел літосферних деформацій є власні коливання рівня рідини у великих водоймах. Розглянуто ідею використання ефекту резонансу припливно-сейшових вібрацій для ініціювання слабкої сейсмічності. Штучно збудження сейш досягають, керуючи водопропускною гідроспорудою. Мережа передавання інформації підтримує мультиплексування каналів зв’язку з розділенням за фізичною природою і середовищами передавання. Під час управління водопропускними спорудами здійснюється штучне розгойдування сейшових коливань зі зсувом фази. Зсув фази розгойдувальної хвилі щодо тієї, що загасає, зумовлює варіації періодів сейш, що призводить до пропорційних варіацій періодів мікросейсмів. Це рішення дозволяє кодувати повідомлення тривалостями періодів сейш і мікросеймів, з подальшим їх передаванням. Гідрологічні спостереження виявили ефект залежності періодів поверхневих сейш від глибини води. Виконання зворотного завдання, за виміряного періоду сейш, дає змогу розрахувати глибину водойми. На додаток до безпосереднього вимірювання глибини запропоновано спосіб віддаленого вимірювання, що використовує аналіз коливань ґрунту сейшового походження. Аналіз варіацій електромагнітного випромінювання геологічного середовища показав, що вони визначаються механізмами перетворення енергії цих процесів на енергію електромагнітного поля. Дослідження цих варіацій дає змогу розрахувати глибину водойми. *Наукова новизна*. Детально розглянуто способи використання збуджених стоячими хвилями мікросейсмічних коливань. Подано способи управління стоячими хвилями: регулюванням глибини водойми; регулюванням періоду збуджувальної хвилі; регулюванням фази збуджувальної хвилі. Досліджена залежність амплітуди результуючого коливання стоячих хвиль від фази розгойдувального коливання аналогічного періоду. Наведено захищені патентами України інноваційні розробки, які передбачають господарське використання мікросейсмів, спричинених стоячими хвилями водойм. Зазначено, що як необхідність, так і можливість використання того чи іншого способу виконання конкретної задачі визначаються внутрішніми та зовнішніми об’єктивними умовами, які існують в певний час в певному просторі.

Ключові слова: затухання хвиль; збудження хвиль; сейші; тягун; розгойдування хвиль.

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