ISSN 8755-6839

SCIENCE OF TSUNAMI HAZARDS

Journal of Tsunami Society International

Volume 37 Number 3 2018

EVALUATION OF TSUNAMI DANGER FOR THE WESTERN COAST OF THE BLACK SEA BY POSSIBLE CATASTROPHIC UNDERWATER EARTHQUAKES

R.Kh.Mazova[1], Kolchina E.A.[2],

[1]R.E. Alekseev Nizhny Novgorod State Technical University, Nizhny Novgorod, Russia, e-mail: raissamazova@yandex.ru
[2]LCC SPE Prima, Nizhny Novgorod, Russia, kolchinaelena@yandex.ru

ABSTRACT

The present study deals with the numerical simulation of generation and propagation of tsunami waves from hypothetical earthquake sources along the western coast of the Black Sea. Potential strong earthquakes with a magnitude M = 7.3 with sources localized both in the regions of historical earthquakes and regions determined by the basic geostructures of the Caucasian and Crimean coasts are considered. The mechanism of earthquake realization is considered in the framework of the keyboard block model of the earthquake source. The source is assumed to be three-block, with different character of the motion of the keyboard blocks for each of the considered scenarios of the earthquake. For each scenario, numerical simulation of tsunami source generation and further tsunami wave propagation to the west coast were carried out. Histograms of the wave height distribution along the entire coastline were obtained, and the results obtained were compared to determine the most dangerous parts of the coast from strong earthquakes. The wavelet analysis of the wave characteristics obtained for each scenario was carried out. Wave fields near the cities of Varna and Odessa are analyzed from far-fleld and mid-field seismic sources and the intensity of wave processes is estimated.

Key words: *earthquake source, tsunami waves, numerical simulation, histograms of the wave height distribution, spectral characteristics of the wave field .*

INTRODUCTION

It is well known that the western part of the Black Sea is blocked off the eastern part by an underwater ridge, and, as noted in [1]: "Tsunami sources in the eastern part of the sea almost do not transmit wave energy to its western part (Fig. 1) . And conversely, the waves excited in the western part of the sea are relatively weak in its eastern part. This depression is separated from the similar West-Black- Sea depression by the subcontinental block of the earth's crust - the Andrusov ridge, extending in the meridional direction from the southern coast of Crimea almost to the coast of Turkey.

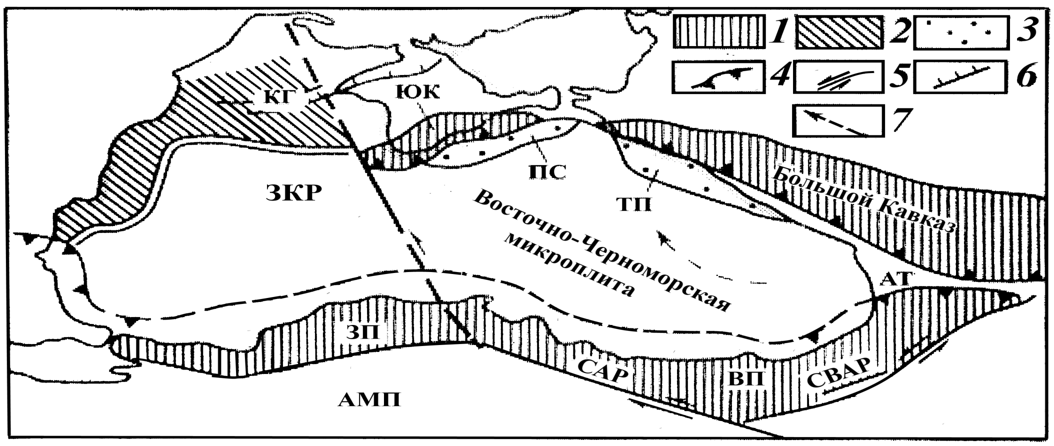

Fig. 1. The Eastern-Black-Sea microplate [2].

The figure above shows the schemes of active faults in the Crimean-Caucasian region, which depict different types of faults on the earth's crust [2]. As follows from these works, seismically active regions in this region are located in the north-east, south and south-west of the Black Sea depression, and in the northwestern region, in fact, earthquakes are rare. However, events like tsunami on the north-west coast were observed, both in the past centuries, and in the present one. So, on January 23, 1838 in the Odessa harbor, the intense excitement of the sea destroyed the ships. Apparently, this was due to an earthquake with a magnitude of M = 6.9 [3,4]. Already in our century on July 5, 2007, an event like a tsunami occurred on the Bulgarian Black Sea coast: "The excitement of the sea like a tsunami lasted several hours, small fishing boats were thrown on the beach of Balchik and Kavarna [5]. Figure 1 clearly shows that the Black Sea basin is divided into two parts: the West Crimean fault, which can be traced on the Odessa shelf and acts as a transfer zone. It is assumed that the West Crimean fault connects to the North Anatolian fault in the region to the south of Sinop (Fig.1) [2]. Thus, this fault plays the most important role of the largest transformational structure in the Black Sea basin [2]. The principal feature of the research carried out in this work is associated with the generation of tsunami waves by a kinematic source, considered in the keyboard model of the earthquake [6,7]. In contrast to the traditional formulation of tsunami studies in the Black Sea (piston source [8-13]), and from sources whose shape is a function of time [1; 14-17], seismic source consisting of several keyboard blocks are considered taking into account the kinematic and dynamic processes occurring in them during the earthquake [18-20]. Those, the movement of blocks with different directions of velocities up or down relative to the initial position of the sea bottom before the seismic shock is considered. The direction of movement in the source is consistent with the typical directions of ups and downs in historical sources, with the closest localization to the considered region of earthquakes [18-20]. To analyze the nature of tsunami source generation by a seismic source and the character of wave processes in a given water area, three types of model sources localized both in the regions of historical earthquakes and in "seismic gaps", determined by the basic geo-structures of the Caucasus and Crimean coasts [2; 21; 22] are considered.

1. Numerical simulation of generation and propagation of tsunami waves

. A nonlinear system of shallow water equations in a two-dimensional formulation (see, for example, [18, 19]) was used to describe the process of generation and propagation of a wave caused by movements of keyboard blocks in a seismic source, taking into account dissipative effects and bottom friction.

$$\begin{cases} \dfrac{\partial u}{\partial t} + u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y} + g\dfrac{\partial \eta}{\partial x} = f_1 \\ \dfrac{\partial v}{\partial t} + u\dfrac{\partial v}{\partial x} + v\dfrac{\partial v}{\partial y} + g\dfrac{\partial \eta}{\partial y} = f_2 \\ \dfrac{\partial \eta}{\partial t} + \dfrac{\partial}{\partial x}[(\eta + H - B)u] + \dfrac{\partial}{\partial y}[(\eta + H - B)v] = \dfrac{\partial B}{\partial t} \end{cases} \qquad (1)$$

x, y are the spatial coordinates along the axes Ox and Oy, respectively, t is the time; $u(x, y, t)$, $v(x, y, t)$ are the velocity components along the Ox and Oy axes; $\eta(x, y, t)$ is the perturbation of the free surface with respect to its quiet level; H is the maximum depth of the basin, $B(x,y,t)$ is the change in the bottom of the basin (accounting characteristics of the dynamic seismic focus); g is the acceleration of gravity, where $f_1 = \dfrac{-C_h}{H+\eta} u\sqrt{u^2+v^2}$, $f_2 = \dfrac{-C_h}{H+\eta} v\sqrt{u^2+v^2}$ are the bottom friction coefficients, C_h –is the bottom friction coefficient. In the numerical solution, we used a scheme constructed by analogy with the scheme [23]. For modeling, the Black Sea bathymetry was used with a resolution of 500 m. The simulation was performed with a time step of

1 s. In the last seaward point, at a depth of 4 m, the condition of total reflection is set, allowing to fix at this depth the maximum and minimum values of the shift of the wave level. Using this data, it is easy to determine the maximum value of the runup on the coast (see, for example, [24, 25]).

The effect of the transform structure of the Black Sea basin on the formation of wave fields near the cities of Varna, Odessa, Yevpatoriya, Yalta and Feodosiya is analyzed from seismic sources located on both sides of the fault, using a complex keyboard block source of the earthquake. Both near-field and far-field seismic sources were considered. The nature of the movement of the blocks is shown in Table 1. Four scenarios for generation of tsunami waves by seismic sources A, B, F, G (see Fig.2) are considered, consisting of three blocks located on both sides of the fault.

Table 1. Block motion characteristics.

Number of block	1	2	3
Initial time of block motion , T_0 (c)	0	20	10
Final time of block motion, T (c)	10	50	20
Block uplift time, B (м)	1.75	1.75	1.75

It is important that, one of the source (source G) is located directly in the zone of the ridge. In all scenarios, a strong earthquake with a magnitude of M = 7.3 is considered.

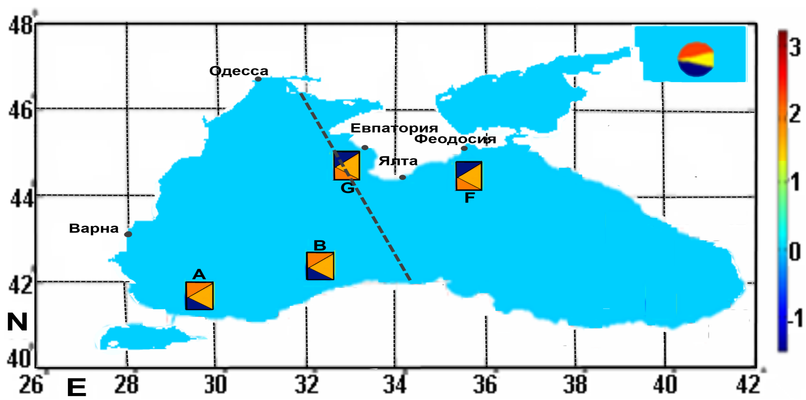

Fig. 2. The East-Black-Sea microplate with hypothetical seismic source [19,20].

The figure shows a schematic representation of the Black Sea basin, divided into two parts by the West Crimean fault with hypothetical seismic source [19,20].

Scenario 1. The generation of a tsunami wave by a seismic source A, located in the south-west of the water area is considered. It is clearly seen from Fig. 3 that at the 400th second we have a uniform circular wave front, 1 m high, towards the west coast and a wave front with a height of more than 3 m to the nearest south-west coast.

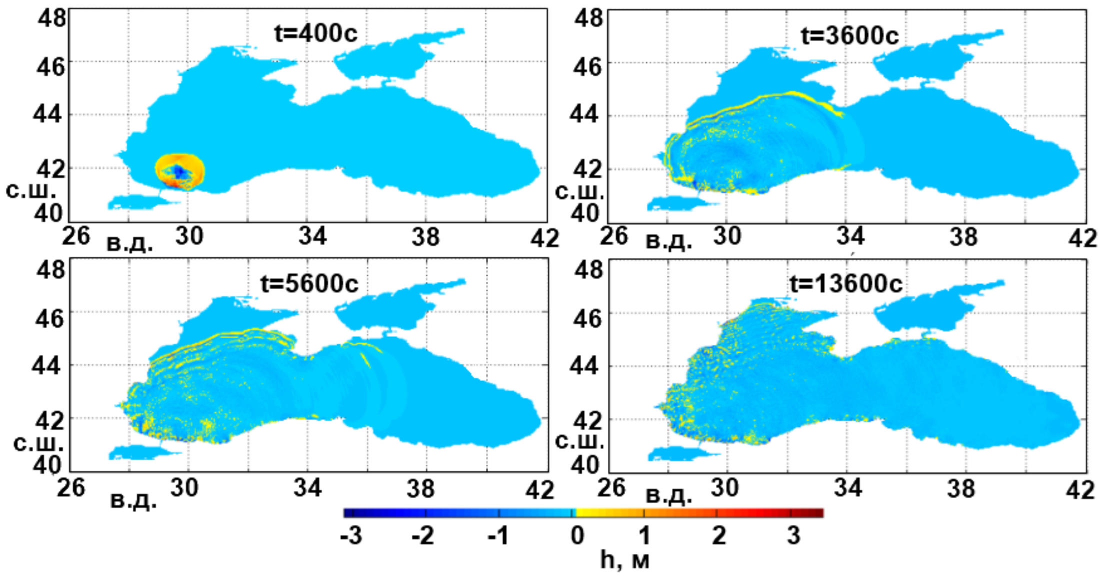

Fig. 3. The characteristic position of the wave fronts for 4 time moments: t = 400 s, t = 3600 s, t = 5600s, t = 13600 s for the seismic source A.

After about an hour the wave front with a wave height of up to 0.8 m, reaches the city of Varna and a 10cm front approaches Yalta; in an hour and a half the wave of 40 cm will approach the city of Yevpatoriya. To Odessa, a wave of 40cm will fit in 3.5 hours. In all the points considered in this scenario, the first wave will approach the beach with the crest (Fig. 3).

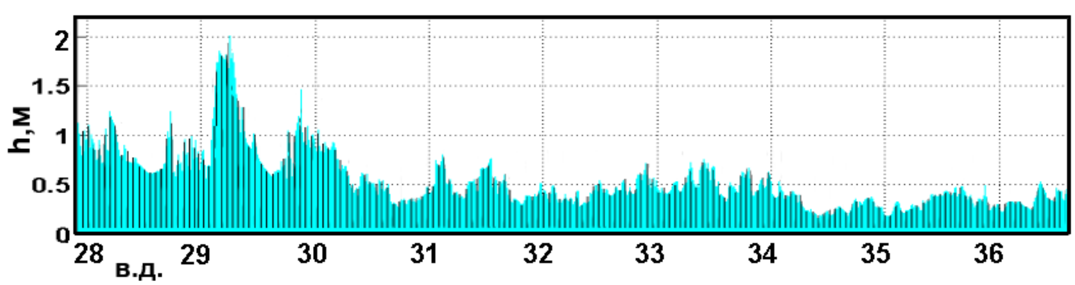

Fig. 4. A histogram of the maximum wave height distribution for the source A.

Figure 4 clearly shows that the maximum of the wave heights in the western part of the Black Sea coastline considered is, on average, about 1 m, and in some areas even of 1.8 m-2 m. At the same time, in the eastern part of this region, the maximum wave height in average is about 0.5 m and there are only a few local maxima not exceeding 0.7 m.

Scenario 2. In this scenario, the generation of a tsunami wave by a seismic source B located also to the west of the underwater ridge. At the 400th second, we have an almost circular wave front with a height of up to 1.5 m. Two distinct fronts reaching the western and north-western coasts are clearly visible. Unlike the previous computation, the wave heights approaching the selected points on the coast will be significantly lower. Figure 5 shows the positions of the wave fronts for 4 time moments.

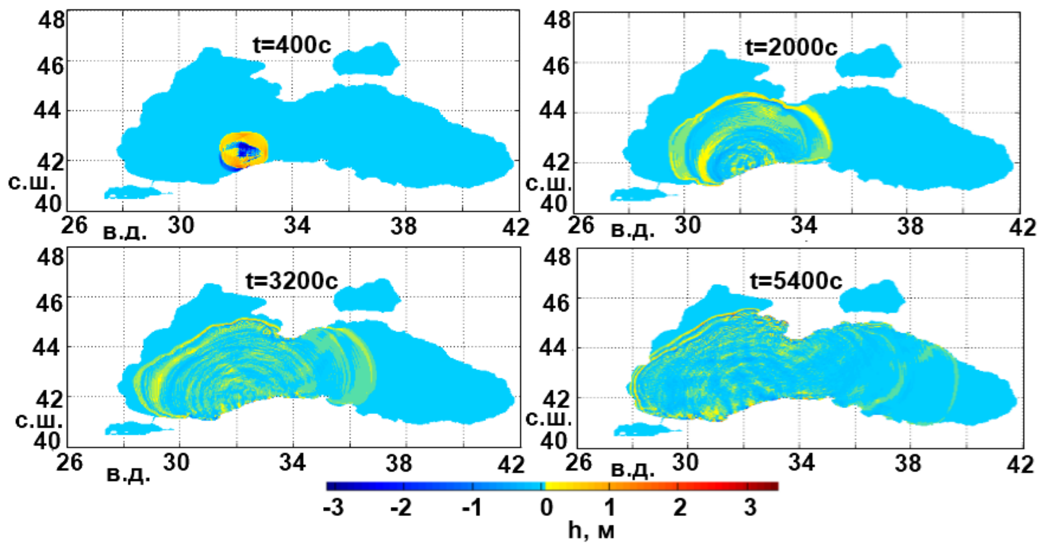

Fig. 5. Characteristic position of the wave fronts for 4 time moments: t = 400 s, t = 2000 s, t = 3200 s, t = 5400 s for the seismic source B.

In contrast to the previous scenario, where a local peak up to 2 m high is located in a direction perpendicular to the location of the source [26], in this case there is no (Fig. 6). The distribution of the maximums of the wave heights is uniform throughout the considered coastline and averages about 0.8 m.

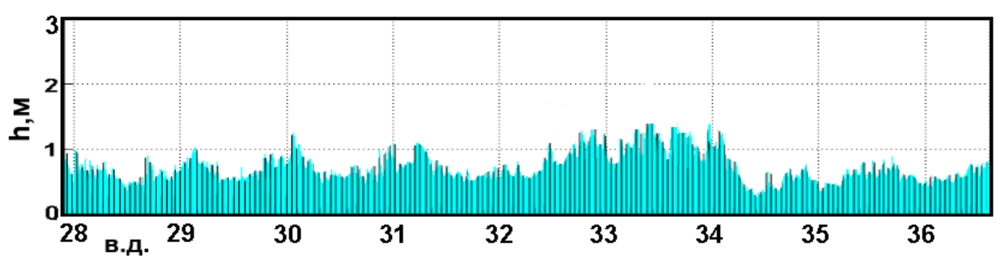

Fig.6. The histogram of the maximum wave height distribution of the (source B).

Scenario 3. The generation of a tsunami wave by a seismic source F located east of the ridge is considered. The source is set in such a way that the movement of one of the blocks downward is oriented towards the shore. In Feodosiya, the first wave will be a wave of rundown (the mareograms are shown in Fig. 7).

The next positive crest will reach 1.7 m. To the cities of Yevpatoriya and Yalta, a wave with a maximum height of 20-30 cm is suitable. In points near the cities of Odessa and Varna, the wave is practically not observed.

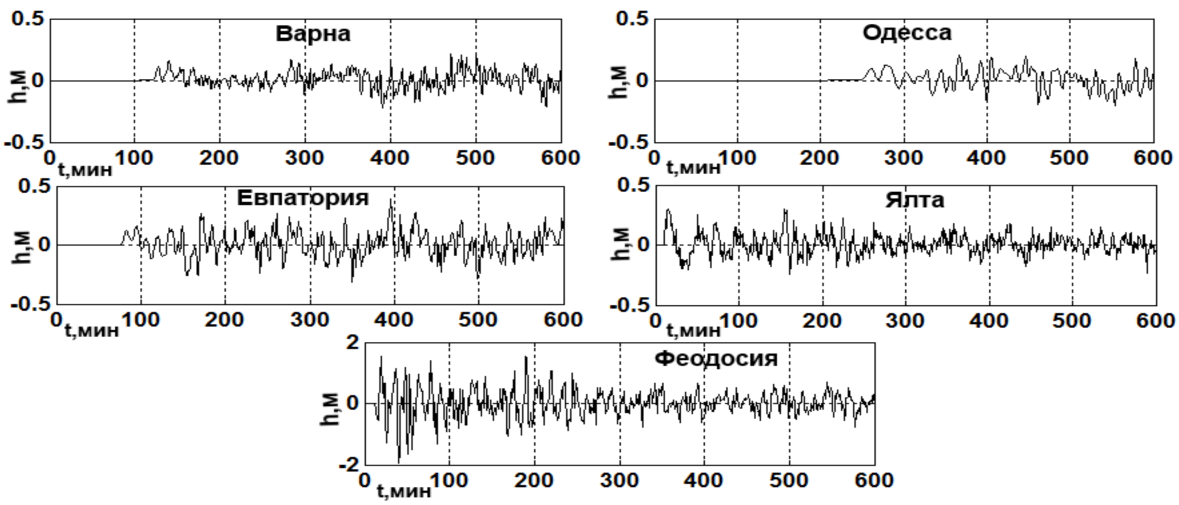

Fig. 7. Tide-gauge records for 5 points of Ukrainian and Bulgarian coasts for the source F.

In the western part of the Black Sea, the maximum wave height is 20-30 cm (Fig.8.). In the eastern part, the maximums of wave heights increase and range from 1 m to 3 m in the region of the local peak.

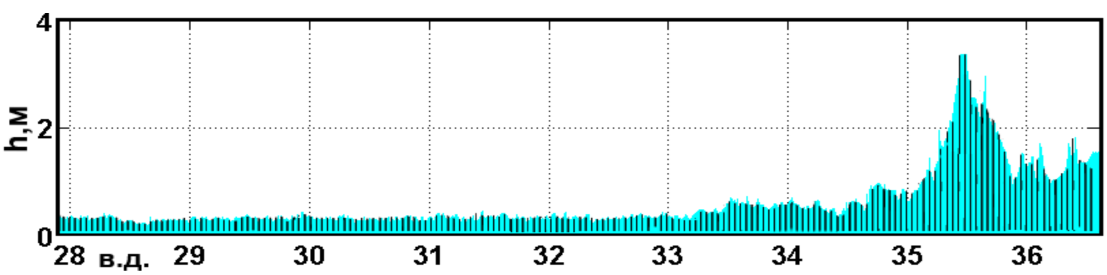

Fig. 8. The histogram of the maximum wave heights distribution for the source F.

Scenario 4. In this scenario, the source G is localized in the zone of the underwater ridge, i.e. one of the source blocks is located to the left of the ridge, and the location of the rest corresponds to Fig. 9, which shows the location of the main geostructures in the Crimean and Caucasian coasts of the Black Sea. To the coast of Yevpatoriya, the first wave comes back, after it 2 m wave is going: to the cities Yalta and Feodosia a 10-15 cm wave is coming.

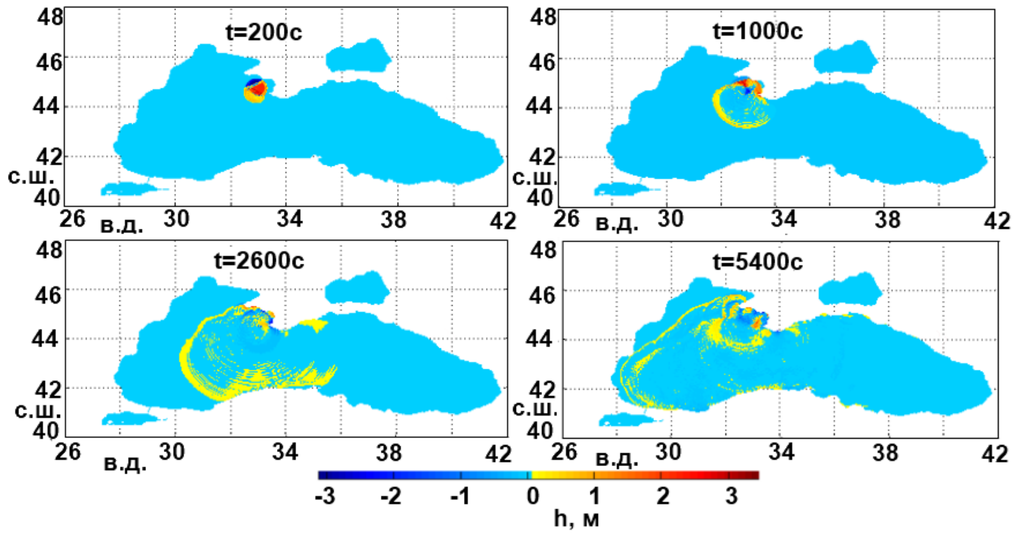

Fig. 9. The characteristic position of the wave fronts for 4 time moments: t = 200 s, t = 1000 s, t = 2600 s, t = 5400 s for the seismic source G.

To Odessa, the wave approaches a positive crest, and the maximum wave, about 1 m, was not the first wave (Fig. 9). Positive wave crest with 10-30 cm high approaches the city of Varna. At a time of about 40 minutes, a well-formed front is visible, moving to the west coast of the water area. After an hour and a half two well-defined fronts are formed, the first of which reaches the coast near the city of Varna.

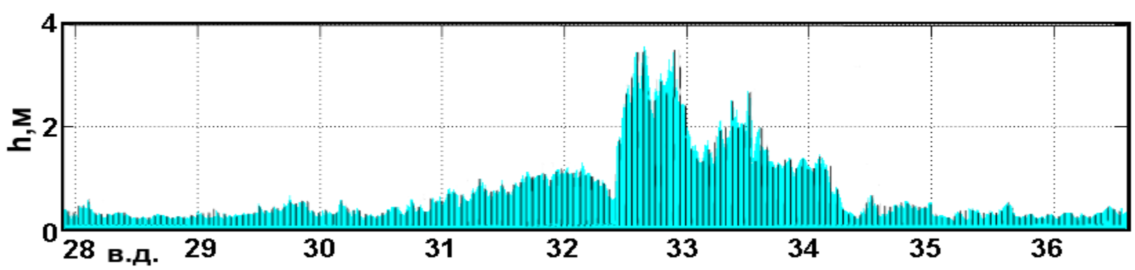

Fig.10. The histogram of the maximum wave heights distribution of the (source G).

Fig. 10 clearly shows that in the vicinity of 32.30 E. a dip is observed and at the west the maximum wave heights do not exceed 1 m, however, from 32.30 E. up to 33.50 E wave heights reach 2.5 m and 3.5 m.

Table 2. Maximum wave heights for 4 scenarios in five cities: Varna, Odessa, Evpatopiya, Yalta, Feodosiya

City	Maximum wave (m) at 4m isobate			
	source A	source B	source F	source G
1. Varna	0.8	0.5	0.1	0.3
2. Odessa	0.3	1	0.1	1
3. Evpatoriya	0.4	1	0.3	2
4. Yalta	0.1	0.2	0.25	0.15
5. Feodosiya	0.2	0.6	1.7	0.1

From Fig. 11 and Table 2. it is clear that the maximum wave heights on the north-west and west coasts do not exceed 2.1 m from the far-field A and B sources. At the same time, the distribution of the maximum wave heights from B is uniform and equals 0.8- 0.9 m.

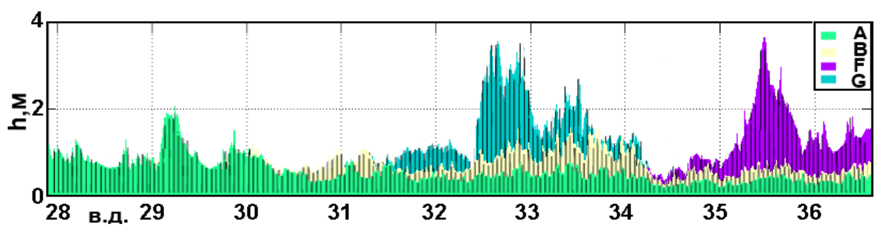

Fig. 11. A histogram of the maximum wave height distribution along the Black Sea coast for A, B, F, G sources.

When calculating tsunami from near-field F and G sources (considering that the keyboard source of the elliptical shape was considered, which does not give an additional refraction contribution from the corners), the maximum wave heights reach 3.5 m.

2. Spectral analysis of possible catastrophic tsunamis for western Black Sea coast.

Using the results of above computations for the generation and propagation of tsunami waves in the water area, a one-dimensional and two-dimensional (wavelet) spectral analysis was performed and the spectral characteristics of tsunami waves were obtained in a given area of the water basin [27, 28]. To analyze the propagation of energy in the water area from the far-field and mid-field seismic sources G, F and B (see Fig. 2), the wave fields near the cities of Varna and Odessa are analyzed. Fig. 12 shows the calculated tide gauges from a virtual tide gauge located in the seaside point near Varna, on a 4 m isobath. The wavelet spectrograms constructed for it from far-field and mid-field seismic sources are shown in Fig. 12 (a, b, c).

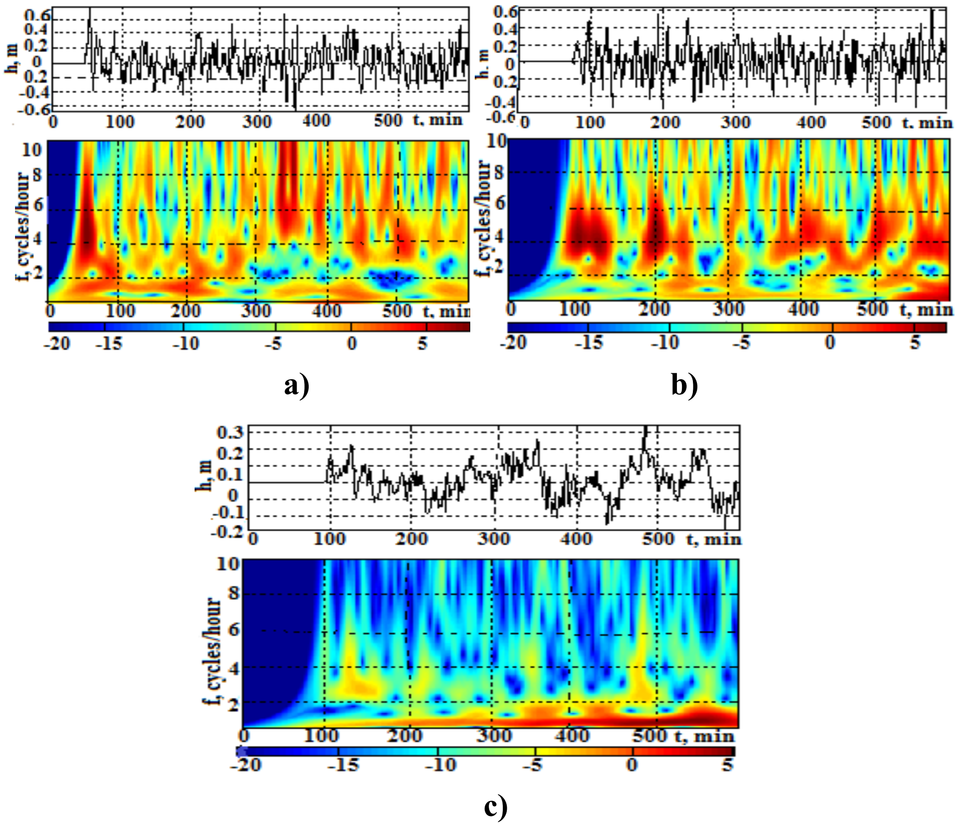

Fig. 12. Tide-gauge records and wavelet-spectrograms for the city of Varna from seismic sources: a) for the mid-field source B; b) for the far-field source G; c) for the far-field source F.

For the source B: The largest amplitude of waves on the 4th isobath is 70 cm. The wave reaches the tide gauge in 40 minutes. It follows from the calculations of the spectra that there are two powerful outbursts at intervals of 30 to 70 min in the range 3.5 to 8 cycles/hour (cph) (waves with duration 17-8 min) to 10 dB and at the interval 340-360 min from 4 to 10 cph, i.e. for 15-6-minute waves, with an energy of up to 8 dB. Those, the most intense are waves with a duration in the range of 6-17 min, which is in good agreement with the tsunami process. Also, in the calculated spectrum, three regions of low-frequency components of a weaker intensity are obtained up to 5 dB with frequencies from 1 to 2 cph at intervals from 20 to 100 min, from 170 to 240 min and from 400 to 480 min, a large fraction of the energy is concentrated in the high-frequency region from 6 to 10 dB.

For the source G: The largest amplitude of the waves on the 4th isobath is 55 cm, however, the amplitude of the first wave is not more than 20 cm. Due to the location of the source, the wave comes to the point 40 minutes later than from the source B. Calculation of the spectrogram shows that in this case the main energy is localized in two regions - in the interval from 80 to 140 min and 180 - 220 min. In the first case, the energy is concentrated, basically, from 2.2 to 6 cph, i.e. The greatest energy up to 7 dB is carried by 25-10 min of the wave. There are also several areas of lower intensity up to 3 dB for the 3-6 cph range, i.e. for 20-10 min of waves. The picture for high-frequency components is similar to the calculation for the source B, which may indicate significant reflections of waves in the shelf zone.

For the source F: For this point, the source VI is a far-field source. The wave approaches the point in 1 hour 40min. The largest wave amplitudes on the 4th isobath are 35 cm, however, the first wave does not have the maximum amplitude. The greatest energy of waves is concentrated in the range up to 1 to 2 cph from 300 to 600 min, i.e. for 30-60 minute waves. The greatest energy is up to 5 dB from 450 to 580 min. High-frequency components in this case are practically absent.

From this analysis it is clear that even for a strong earthquake the Black Sea coast of Bulgaria will not be exposed to significant danger, long-wave wave components do not concentrate significant energy, which is possibly associated with strong wave refraction. This conclusion agrees well with the conclusions of [24, 25]. For analysis of the northwestern part of the Black Sea coast, a seashore point was chosen, located near Odessa. Tide-gauge records of the computed wave fields from three virtual seismic sources G, F and B, and the wavelet spectrograms corresponding to them, are shown in Fig. 13.

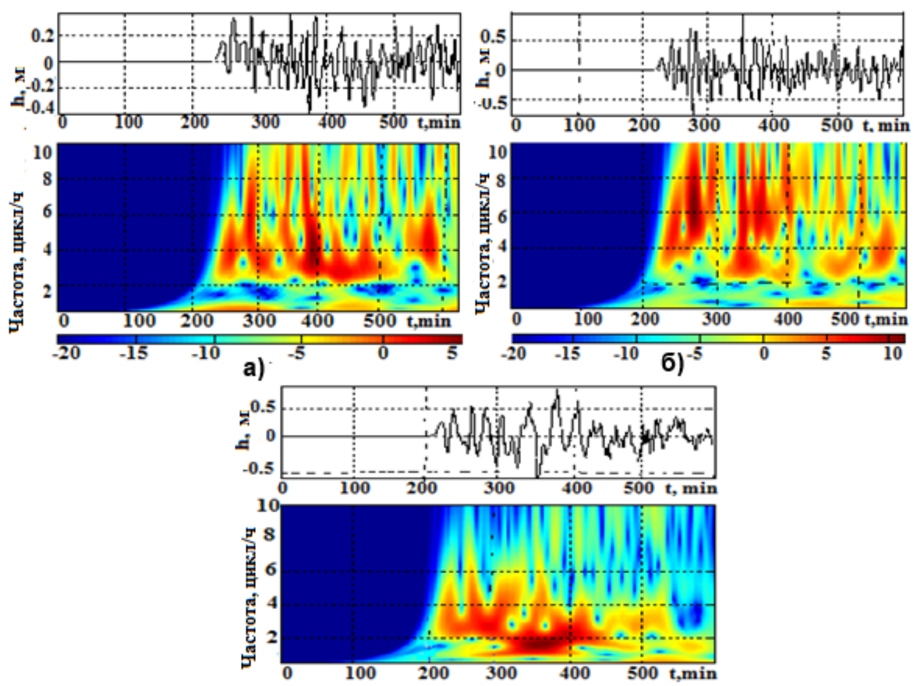

Fig. 13. Tide-gauge records and wavelet spectrograms for Odessa from far-field source: a) for the source B; b) for the source G; c) for the source F.

For the source B: the source of the far-field field, maximum wave amplitudes up to 40 cm. All energy up to 5 dB is concentrated in the region of 370-400 min in the elongated region from 2.5 to 5.7 cph, which corresponds to waves of duration from 10 to 24 min. Areas of lower intensity are almost evenly distributed over the interval 220-500 min. At 280 min, 350 and 370 min in the range of 2-10 cph, the wave intensity is of the order of 3 dB.

For the source of G: the greatest energy is concentrated in the interval 280-300 min, to 14 dB from 5 to 8 dB, i.e. for waves with a duration of 5 to 7.5 min. A smaller intensity of up to 8 dB is observed in the interval from 230 to 320 min, and from 350 to 430 min. The energy is evenly distributed over all frequencies from 2 to 10 cph.

For the source of F: the greatest energy is concentrated in the interval 340-400 min to 20 dB for frequencies from 1 to 2 cph, which corresponds to durations of 30-60 min.. Intervals with lower intensity are also observed in the regions from 220 to 320 min and from 370 to 450 in the 2-4 cph, including some localized regions of zero intensity.

CONCLUSIONS

Thus, even for a strong earthquake with a magnitude of M = 7.3, the points located on the western coast of the Black Sea will not be seriously endangered, the long-wave components will not have significant energy for large damages on the shore. The obtained values of the maximum wave heights are directly related to the choice of the scenario for the realization of an earthquake in hypothetical seismic sources, in those cases when the first vertical downward movement in the source is oriented toward the coast. Such an implementation of the earthquake leads to the appearance of a negative wave front (a depression wave) directed toward the coast. As shown in [29, 30], in this case a substantial increase in the wave extending to the shelf is possible. In addition, the recalculation from the isobath to the dry shore leads to a significant increase in the height of the wave. In this connection, the values of the calculated wave heights from the model seismic sources on the 4-meter and 10-meter isobath given in the work can be considered as the lower estimate for determining the wave heights on the shore. The spectral analysis showed that the largest wave energy will be mainly concentrated in the low-frequency component of the spectrum, which corresponds to wave periods of the order of 12-30 min. The most dangerous in this case are near-field seismic sources, in which the greatest intensity of wave energy can reach 50 dB. However, spectral analysis showed that the energy of the approaching wave and the localization of the epicenter of the earthquake are not correlated.

ACKNOWLEDGEMENT

This work was supported by a grant from the Russian Science Foundation (project No. 14-50-00095).

REFERENCES

1. Dotsenko S.F., Solovyov S.L. On the role of residual displacements of the ocean floor in the generation of tsunamis by underwater earthquakes // Oceanology v.35, No. 1, P.25-31, 1995.
2. Kazmin V.G., Lobkovsky L.I., Pustovitenko B.G., Modern kinematics of microplates in the Black Sea-South Caspian region, Okeanologiya v.44 No. 5. pp. 600-610. 2004.
3. Solovyeva O.N., Dotsenko S.F., Kuzin I.P., Levin B.V., Tsunami in the Black Sea: historical events, seismic sources and patterns of distribution // Oceanology v. 44. No. 3. p.679-685. 2004.
4. Pelinovsky E.N., Preliminary estimates of tsunami for the northern Black Sea, Phys. Chem.Earth v. 24A. P. 175-178. 1999.
5. [http://bg-faq.astrela.com/nature/tsunami_tidal_wave.htm].
6. Lobkovsky L.I., Baranov BV Keyboard model of strong earthquakes in island arcs and active continental margins // Doklady of the Academy of Sciences of the USSR. V. 275. № 4. P. 843-847. 1984.
7. Lobkovsky L.I., Kerchman V.I., Baranov B. V., Pristavkina E.I. Analysis of seismotectonic processes in subduction zones from the standpoint of a keyboardmodel of great eartgquakes // Tectonophysics V.199, P.211-236, 1991.
8. Basov B.I., Kajstrenko V.M., Levin B.V., Poplavsky A.A., Simonov K.V., Kharlamov A.A. Some results of physical modeling of the processes of excitation and propagation of tsunami // in: Tsunami Generation and Wave Emission on the Shore, M .: Radio and Communication, 1984, P.68-72.
9. Gusyakov V.K., Chubarov LB. Numerical simulation of tsunami excitation and propagation in the coastal zone. Izv. AN SSSR. Physics of the Earth v.21, No. 11, P. 53-64, 1987.
10. Dotsenko SF, Sergeevsky B.Yu., Cherkesov L.V. Generation of spatial tsunami waves by bottom motions of finite duration // Tsunami Studies No. 2, Moscow: Nauka, 1987, p. 27-34 (in Russian).
11. Zaitsev A.I., Kozelkov A.S., Kurkin A.A., Pelinovsky E.N., Talipova T.G., Yalchiner A.S., Tsunami modeling in the Black Sea // Izvestiya AIIN RF, PMM T. 3. P. 27-34. 2002.
12. Levin B.V. A review of the work on the experimental modeling of tsunami excitation // in the book: Methods for calculating the origin and distribution of tsunamis. Moscow: Nauka, 1978, p.125-139 (in Russian).

13. Levin B.V., Nosov M.A. Physics of tsunami // M .: Janus-K, 2005.- 360 p.
14. Dotsenko S.F. Excitation of tsunami waves in continuously stratified motions of the bottom section // Tsunami Studies No. 3, Moscow: MGFK under the Presidium of the USSR Academy of Sciences, 1988, p.7-17.
15. Nosov M.A. Comparative analysis of excitation of tsunami by piston and running shifts of the bottom // Volcanology and seismology № 6, C.70-75, 1995.
16. Okada Y. Surface deformation due to shear and tensile faults in a half space // Bull.Seismol.Soc.Am., V.75, P.1135-1154, 1985.
17. Rangielov B., Possible tsunami deposits discovered on the Bulgarian Black Sea coast and some implications. // in: Submarine Landslides and Tsunamis (Kluwer Acad.Publ., 2003), P. 237-242.
18. Mazova R.E., Tresvyatskaya E.A. Numerical Simulation of Long Water Wave Generation by Dynamic Seismic Source and Their Propagation for Black Sea Basin. Russ. J. Earth Sci. V.8, ES5001, doi: 10.2205 / 2006ES000208 http: //dx.doi. org / 10.2205 / 2006ES000214 (2006).
19. Mazova R.Kh., Kiselman B.A., Kolchina E.A. Numerical simulation of tsunami wave height distribution for the Turkish Black Sea coast in the nonlinear dynamic keyboard of the underwater seismic source // J.of Comp.and Appl. Math., V.259, P. 887-896 (2013), http: //dx.doi .org / 10.1016 / j.cam.2013.08.034
20. Mazova R.KH., Kiselman BA, Osipenko NN, Kolchina E.A. Analysis of spectral characteristics of the Black Sea tsunami / / Proceedings of Nizhny Novgorod State Technical University. R.E. Alekseeva, 2013, No. 2 (99), P.52-66.
21. Chebanenko, I.I. Scheme of deep faults on the Crimean and Caucasian coasts of the Black Sea / II. Chebanenko, et al., Geol. journal. 2003. № 1. P. 54-58.
22. Soloveva, ON Seismicity and tsunami of the north-eastern part of the Black Sea / O.N. Solovyov, I.P. Kuzin // Oceanology. 2005. №45. Pp. 826-833.
23. Sielecki A., Wurtele M. The numerical integration of the non-linear shallow-water equations with sloping boundaries // J. Comp. Phys. V.6, P.219-236, 1970.
24. Golubtsova T.S., Mazova R.Kh. The roll of a wave of variable shape // in the book. "Oscillations and waves in the mechanics of a continuous medium", Gorky: ed. GPI, 1989, P.52-63 (in Russian).
25. Pelonovsky E.N., Mazova R.Kh. Exact analytical solutions of nonlinear problems of tsunami wave runup on slopes with different profiles // Natural Hazards V.6, P. 227-241, 1992
26. Nikonov A.A. Tsunami on the shores of the Black and Azov Seas // Izvestiya RAN. Physics of the Earth. T.33. № 1. P. 86 - 96. 1997

27. Vetterli M., Kovacevic J., Goyal V. - Foundation of Signal Processing, Cambridge University Press (ISBN 110703860X), 2013, 707p.
28. Mallat Stephane «A wavelet tour of signal processing» // Academic Press, 1999.
29. Dotsenko SF, Konovalov A.V. Numerical simulation of tsunami wave propagation in the open part of the Black Sea // Marine hydrophysical journal. No. 1. P. 67-80. 1995.
30. Kulikov E.A., Poole S.L., Rabinovich A.B. Spectrum of long waves in the open ocean and radiation tides // in: Wave processes in the northwestern part of the Pacific Ocean, Vladivostok: Fae-East NTS USSR Acad.of Sci., 1980, P.28-38 (in Russian).