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TSUNAMI DANGER IN THE KERCH STRAIT

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ABSTRACT

The numerical simulation of the tsunami wave propagation along the Kerch Strait is carried out with localization of possible sources at the entrances to the strait, both from the Black Sea and from the Sea of Azov. Under computation of both generation and tsunami propagation, a system of nonlinear shallow water equations was used. The potential strong earthquakes (with earthquake magnitude M ~ 7) with seismic sources of elliptical shape were considered. Detailed assessments of the wave characteristics in the Kerch Strait, in particular for the Crimean bridge area, were carried out. The obtained wave characteristics are compared with the available data of the work of other authors.

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

1. INTRODUCTION

As known, the Kerch Strait divides the Kerch Peninsula of the Crimea and the Taman Peninsula of continental Russia. On the other hand, it connects the water areas of the Black and Azov Seas, so that the Sea of Azov, as a relatively small water basin, can in fact be considered as a gulf of the Black Sea. It should be noted that the geological conditions in the Kerch Strait are quite complex - seismicity, tectonic fracture, weak soils. According to hydrogeologists, the Kerch Strait is in fact a place of a tectonic fault, and the Kerch and Taman coasts belong to different tectonic plates. Moreover, in addition to taking into account the possibility of an earthquake in the Kerch Strait itself, it is necessary to take into account the possibility of the appearance of tsunami waves coming from both the Black Sea and the Sea of Azov.

Such the tsunami was recorded on September 11-12, 1927, December 28, 1939 and July 12, 1966, when waves from the Black Sea to the Sea of Azov crossed the Kerch Strait. The echoes of these tsunamis were recorded in a number of points in the Azov Sea [1]. In general, oscillations in the water level in the Kerch Strait are of a different nature, the most significant in magnitude are the surge oscillations [2], which are also characteristic of the Sea of Azov (mini-tsunami). In the southeast of the Sea of Azov in 1969, on October 28, a tsunami struck a five-meter high water wall into the southeastern part of the sea. In 1971, such an event, but on a large scale, was repeated for the same part of the Azov Sea [3]. The tsunami of seismogenic nature in the Sea of Azov is little known [4].

Epicenters of historical relatively weak underwater earthquakes are concentrated in the southern and southwestern parts of the Azov Sea [3 – 6]. The issue of tsunami hazard research in the Black Sea and the Sea of Azov adjoining the Kerch Strait has been given attention in a number of works (see, for example, [4, 6 – 9].) Thus, in [7] a numerical analysis of tsunami wave propagation in the Azov Sea was performed. As noted in this paper, "the issue of the effectiveness of tsunami generation in the Sea of Azov by seismic sources remains relevant and little studied." These issues are now very important in connection with the beginning exploitation of the bridge across the Kerch Strait - the Crimean bridge, the automobile part of which was only recently opened, in May 2018.

In the present work, the tsunami wave propagation through the Kerch Strait is numerically simulated during the localization of possible earthquake sources at the entrances to the strait, both from the Black Sea and from the Sea of Azov. The potential strong earthquakes (with earthquake magnitude M ~ 7) with seismic source of elliptical shape were considered. The real bathymetry of the relief of the bottom of the Kerch Strait, which has a rather complex structure, is used - the transverse profile of the channel of the strait is asymmetric, and the strait itself is delimited by two spits into three parts [10]. Detailed assessments of wave characteristics in the Kerch Strait, in particular for the Crimean bridge area, were carried out.

2. NUMERICAL SIMULATION

As noted in [5], the southern section of the Crimean Peninsula's shelf is one of the most probable zones of seismic generation of tsunamis in the Black Sea. According to [5], it is impossible to exclude the possibility of underwater earthquakes with magnitudes M = 7, 0-7, 5, which can be accompanied by strong tsunami. Since one of the most probable zones of seismic generation of tsunami in the Black Sea is the southern part of the Crimean Peninsula [5], the localization of the seismic source in the Black Sea in front of the Kerch Strait to the northeast of the Crimean Peninsula (Scenario 1) (Fig. 1), and for Scenario 2 (compare [7]) - before entering the Kerch Strait from the Azov Sea side (Fig. 2).

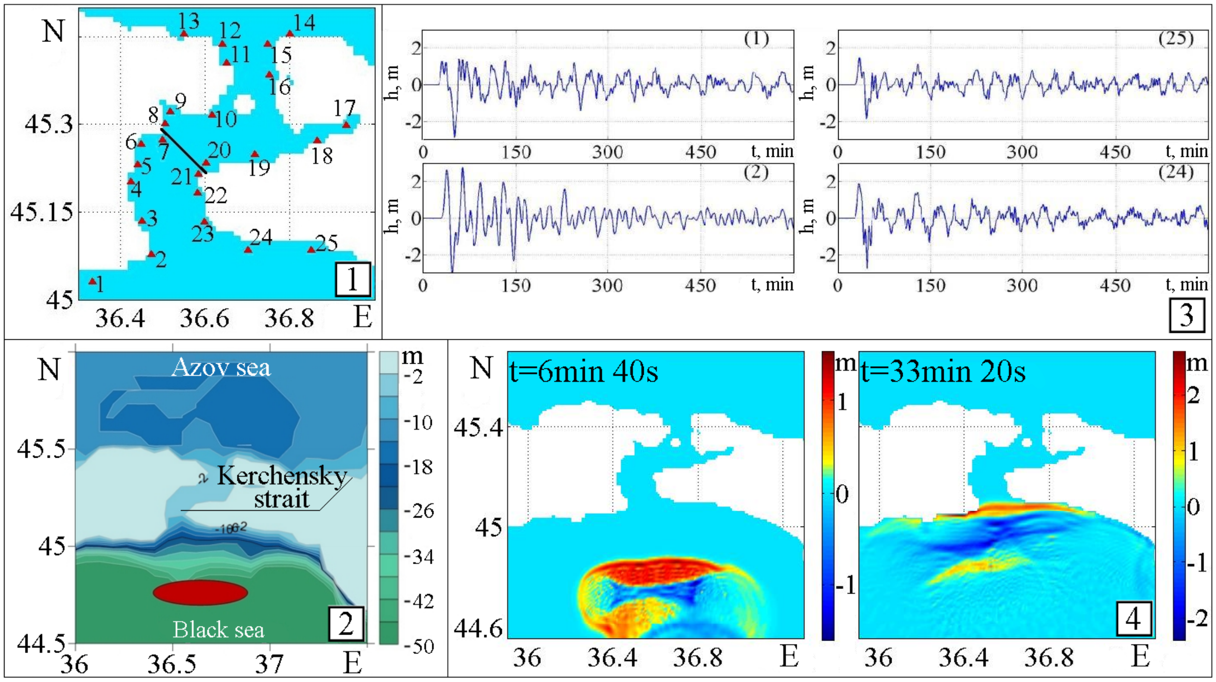

Fig. 1. Schematic representation of the water area of the Kerch Strait and the characteristics of wave fields; in the inset (1): the scheme of the virtual tide gauges along the western and eastern coasts of the Kerch Strait; in the inset (2): the location of the calculated source of the earthquake for Scenario 1; in the inset (3): data from 4 virtual gauges at the entrance to the Kerch Strait from the Black Sea (in the upper right corner there is a virtual tide gauge number): (1) - p. Yakovenkovo, (2) - p. Treasured, (24) - p. The wave, (25) - p. Artyushchenko; in the inset (4): the position of tsunami wave fronts for two time instants.

To simulate possible strong earthquakes with a magnitude of 7, we chose two hypothetical sources of an earthquake, an ellipsoidal shape with dimensions of about 16.4 x 68 km [11]. A nonlinear system of shallow water equations in a two-dimensional formulation (see, for example, [12, 13]) was used to describe the process of generation and propagation of a wave caused by the displacement of seafloor areas in the earthquake source, taking into account dissipative effects and bottom friction. In the numerical solution, we used a scheme constructed by analogy with the scheme in [14]. The design area used for these calculations was selected in a square of 35^0-38^0 (E), 44.5^0-47.5^0 (N), with a grid including the number of nodes 345x361 = 124,545. Black Sea bathymetry with a resolution of 500 m was used for numerical simulation. The simulation was performed with a time step of 1 s [13]. In the last seaward point at a depth of 3 m, the condition of total reflection (vertical wall) is set, allowing to fix at this depth the maximum and minimum values of the shift of the wave level.

In numerical simulation, displacement wave fields and velocity fields were obtained along the northwestern coast of the Black Sea, the coasts of the Azov Sea and along the coasts of the Kerch Strait. The computation area and the layout of the virtual tide gauges along the western and eastern coasts of the Kerch Strait are shown in Fig. 1.1, 1.2. In Fig. 1.3 and Fig. 1.4 there are presented the results of numerical simulation calculations for part of the Black Sea in front of the Kerch Strait. Figure 1.3 shows the computed tide gauge records for points 1, 2, 24 and 25, located at the entrance to the strait (see Fig.1.1). It can be seen that the maximum spread in sea level oscillations in these points is almost 5 m: from +2.3 m to -2.5 m.

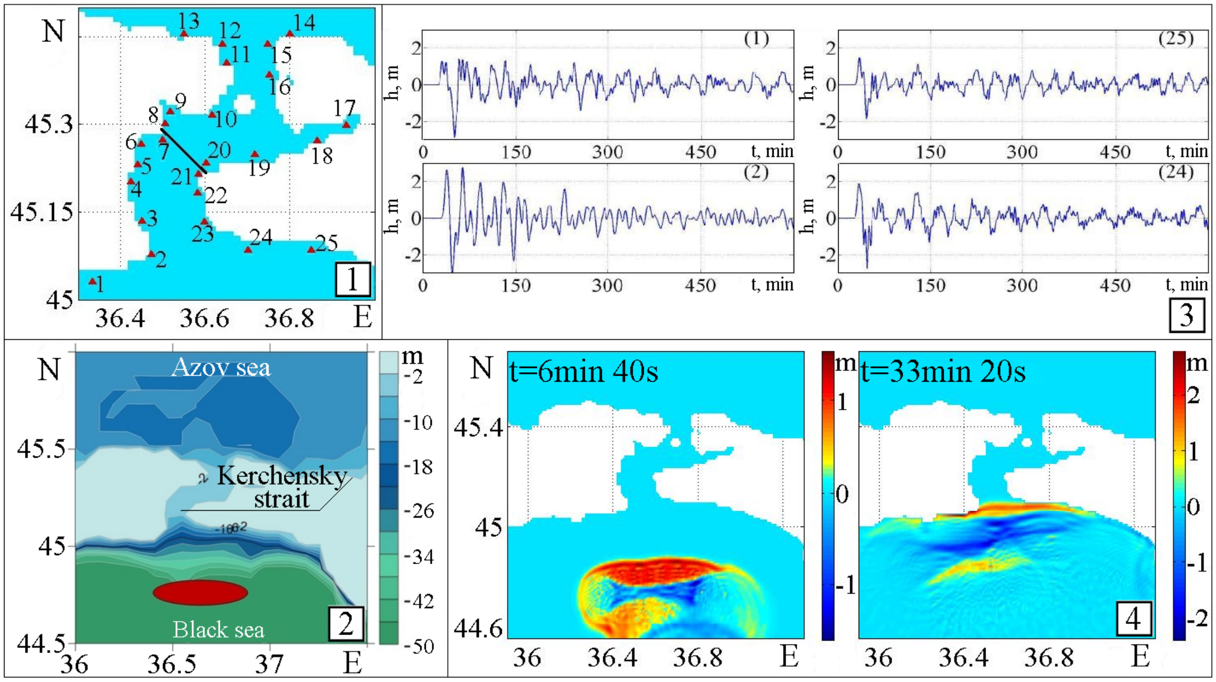

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Figure 2 shows a picture of the propagation of a tsunami wave along the Kerch Strait. When the wave moves in the Kerch Strait, the wave height decreases and the maximum value of the height of the leading edge of the wave becomes in the the order of 1 m. With further motion of the wave, its front after 1 h 10 min reaches first the right support of the bridge, while the maximum wave height remains on the order of 1 m. After 10 minutes, the wave reaches the left support of the bridge with the wave height about 0.7 m. As can be seen from Fig. 2.3 (t = 1h), the leading edge of the elevation wave has a convex, arcuate shape across the entire width of the strait. The height of the crest in the strait, an hour after the start of the event, reaches a meter and a half.

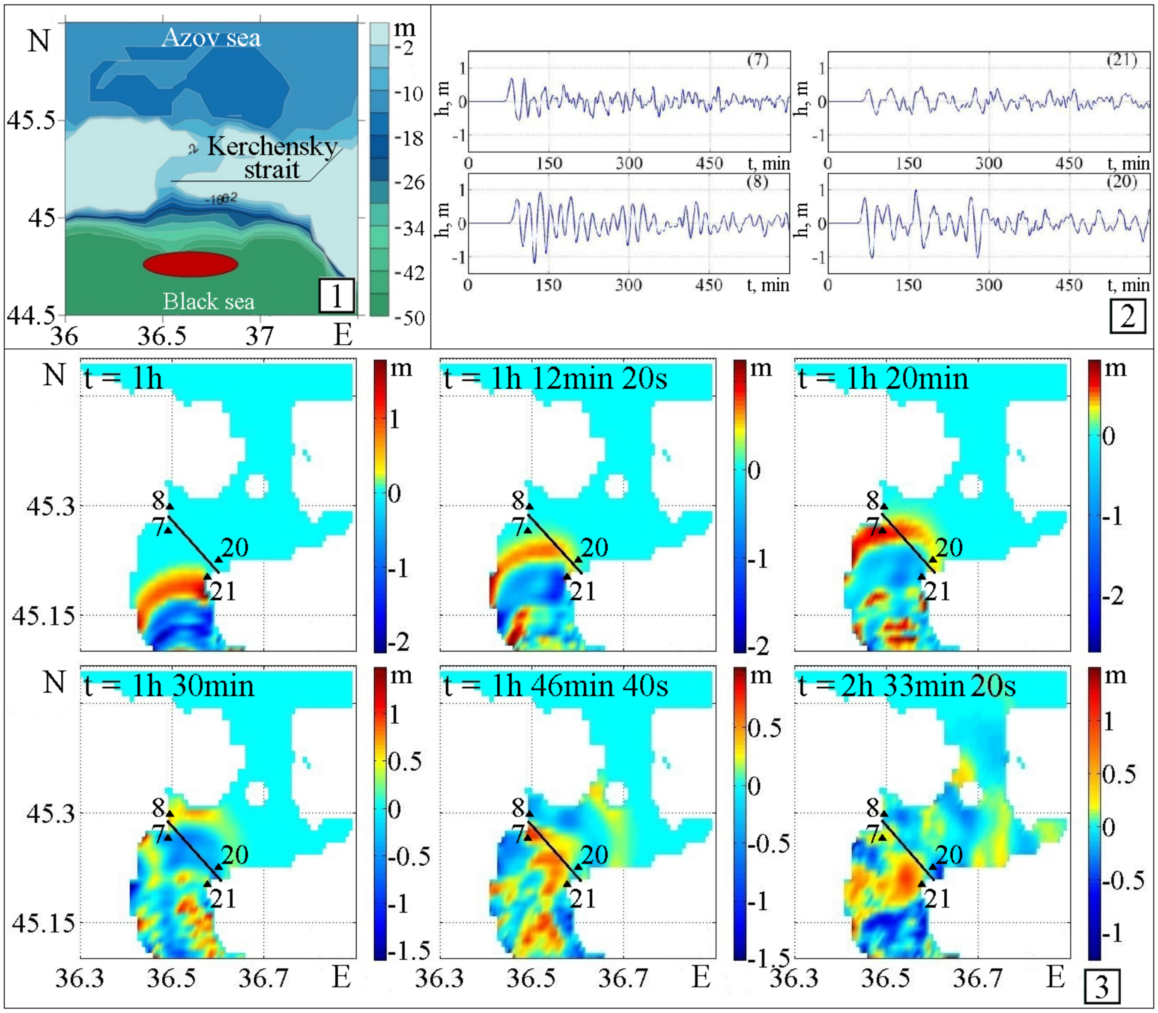


Fig. 2. Characteristics of wave fields in the Kerch Strait basin for Scenario 1; in the inset (1): the location of the calculated source of the earthquake for Scenario 1; in the inset (2): data from 4 virtual tide gauges along the Kerch Strait; (7) - left south edge of the bridge, (8) - left north edge of the bridge, (20) - right north edge of the bridge, (21) - right south edge of the bridge. In the upper right corner is the number of the virtual tide gauge; in the inset (3): the position of the tsunami wave fronts and the distribution of the water level in the Kerch Strait basin for six time moments for Scenario 1. The dark line is a schematic representation of the position of the Crimean bridge.

After 1 hour and 12 minutes, the right edge of the wave front with a height of up to 0.7 m (see point 20 in Fig.2.2.) reaches the eastern bridge supports in the area of the Tuzla spit. The rest of the front continues to spread northward and after 8 minutes attacks the northern coast of Kamysh-Burun Bay and reaches west bridge supports. The height of the wave crest in point 7 (Fig.2.2) is of the order of 0.7 m. After passing the Tuzla spit, the height of the right half of the wave front is almost halved and the wave front is turned towards the Taman Bay (Fig. 2.3, t = 1h 20min). After 1 hour 30 minutes, the middle part of the wave front extends toward the northern coast of the Kerch Bay and reaches it in 10 minutes with a height of about 1 m, t = 1h 20min). At the rest of the bay the runup is about 0.5 m in height. In the vicinity of the bridge, a decrease in the water level by about 1 m is observed at this time. After 15 minutes (Fig. 2.3, t = 1h 46min 40s), a wave crest consisting of two parts approaches the bridge. The center of the bridge is subjected to the attack of a crest of a wave having a pointed shape, precisely in the area of the Tuzla spit, where the eastern pillars of the bridge are located. Another section of the wave front attacks the bridge supports at the site of its bend in the area of the Ak-Burun cape. At the same time, the wave forefront reaches the Chushka spit, but the height of the crest is less than 0.5 m. Approximately 2 hours 30 minutes after the tsunami generation, the Tuzla spit area (Fig. 2.3) is again attacked by waves with a crest height of more than 1 m (Fig. 2.3, t = 2h 33min 20s).

In the case of the implementation of Scenario 2, the picture of the propagating of a tsunami wave along the Kerch Strait is shown in Fig. 3.1. Unlike Scenario 1, the leading edge of the elevation wave after entering the strait and passing the Chushka spit is flat (Fig.3.3). The height of the crest in the strait, one hour after the beginning of the event, reaches about a meter (Fig. 3.2).

After 1 hour and 46 minutes, the wave front reaches the southern coast of the Taman Bay with a crest height of up to half a meter in the Taman region, and also reaches the bridge supports in the Tuzla spit area (see the tide gauge records in points 20 and 21 in Fig.3.2) with wave height up to 0.4 m (Fig.3.3). The rest of the front continues to spread in the south-west direction, reaching the northern coast of the Kerch Bay. Two hours after the generation of the tsunami, the wave front reaches the bridge supports (see the tide gauge records in points 7, 8 and 20, 21 in Fig.3.2) along its entire length and enters the Kerch Bay (Fig.3.3). The wave height reaches 0.4 m in the area of the Tuzla spit, decreasing to 0.2 m near the cape of Ak-Burun. After 15min the wave passes through the bridge, remaining only in the water area of the Kerch Bay.

With further propagation, the wave front becomes more flat with a maximum height of about 0.2 m, reaching the coast of the Kamysh-Burun Bay and further, dissipating through the strait.

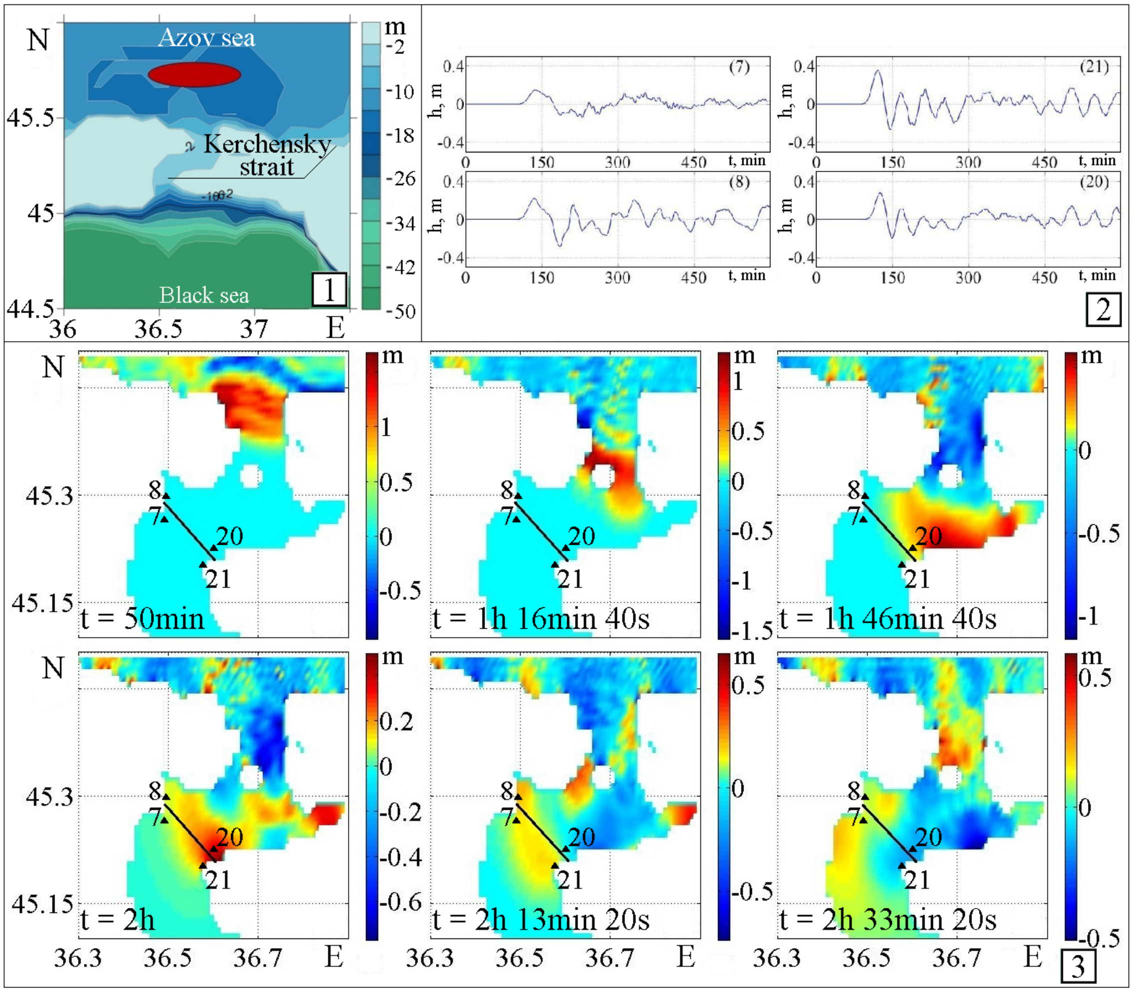
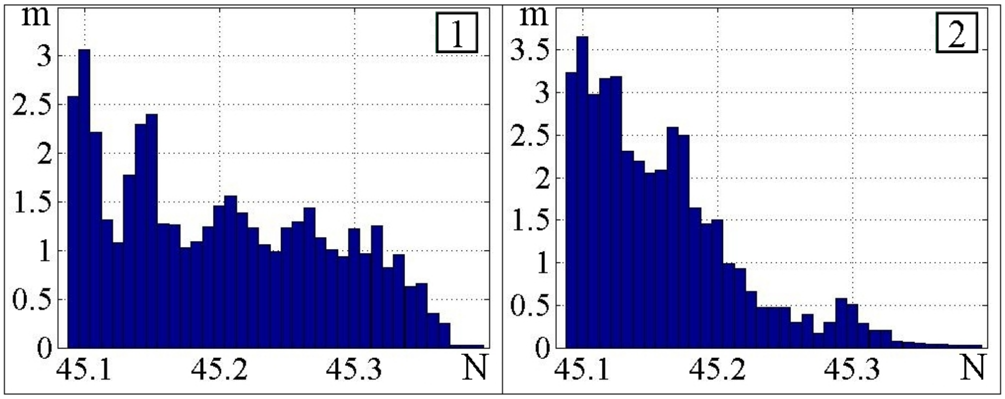


Fig. 3. Characteristics of wave fields in the basin of the Kerch Strait for Scenario 2; in the inset (1): the location of the calculated source of the earthquake for Scenario 2; in the inset (2): data from 4 virtual gauges along the Kerch Strait for Scenario 2; (7) - left south edge of the bridge, (8) - left north edge of the bridge, (20) - right north edge of the bridge, (21) - right south edge of the bridge. In the upper right corner is the number of the virtual tide gauge; in the inset (3): the position of the tsunami wave fronts and the distribution of the water level in the Kerch Strait basin for six time moments for Scenario 2. The dark line is a schematic representation of the position of the Crimean bridge.

Figure 4 shows histograms for the maximum values of wave heights along the western and eastern coasts of the Kerch Strait. The wave heights at latitude 45.3° at the western shore (Fig. 4.1) and 45.2° at the eastern shore (Fig. 4.2) correspond to the maximum fixed rise of the water level at the left and right edges of the bridge, respectively. As follows from the graph, for the left edge this value was 1.5 m, for the right 2 m.



F*ig. 4. Histogram of maximum tsunami heights on a 3-meter isobate for the coast of the Kerch Strait near the Crimean bridge; panel (1): the west coast of the strait; panel (2): east coast of the strait.*

3. CONCLUSION

As can be seen from the calculation, for possible strong earthquakes with magnitude M = 7 in the Black Sea, the height of tsunami waves in the Kerch Strait in the area of the bridge under construction can reach 1.5-2 m. The speed of the water flow in the vicinity of the western bridge supports circumambulating the cape of Ak- Burun, can reach 50 km / h. In the eastern part of the bridge, the Tuzla spit serves as a natural dam, extinguishing the destructive energy of the tsunami. As can be seen from the calculation, for possible strong earthquakes with magnitude M = 7 in the Black Sea, the height of tsunami waves in the Kerch Strait in the area of the bridge under construction can reach 1.5-2 m. The speed of the water flow in the vicinity of the western bridge supports circumambulating the cape of Ak- Burun, can reach 50 km / h. In the eastern part of the bridge, the Tuzla spit serves as a natural dam, extinguishing the destructive energy of the tsunami. After 1 hour and 45 minutes after the tsunami is generated, a crest of a wave up to a meter high approaches the middle of the bridge, while the left side of the wave front attacks the western part of the bridge that surrounds the Ak-Burun cape. To the eastern part of the bridge in the area of the Tuzla spit, a wave up to 1 m high approaches a little later, after 45 minutes. Further propagation of the wave occurs with lower heights. When the problem is posed again, when the potential source of the tsunami is located in the Azov Sea, the wave heights in the Kerch Strait are much less, up to half a meter. The main impact of the wave falls on the southern coast of the Taman Bay, so that when a part of the wave front approaches the bridge line, then its energy is already substantially extinguished. A characteristic feature of the tsunami spreading through the strait is the flat wave front shape as when moving along the Cusca spit, or when approaching directly to the bridge. Unlike the previous source case in the Black Sea, a wave of elevation attacks the bridge across the entire width of the bridge from the Tuzla spit in the east to the Ak-Burun cape in the west. Note that the wave height here is much less than in the first case, however, the whole bridge construction is attacked immediately. The results obtained are in good agreement with both the few observational data and those of other authors (see, for example, [8, 9]).

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