Autonomous Network of Seismic Stations of the Island of Matua

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Abstract. Currently, the majority of seismic stations installed in the Far East automatically continuously transmit data to processing centers. But none of the network's seismic stations is autonomous in the full sense of the word. All these seismic stations are located in places where there is a power supply system and cellular communication. Some seismic stations do not transmit data due to the absence of a cellular network, and are powered by regularly replaced batteries, so they require regular visits to save data and replace batteries.

1. Introduction

Sakhalin Island, the Kuril Islands and the Kamchatka Peninsula have high seismic [1,2,3] and volcanic [4,5,6] activity. For continuous monitoring of seismic activity using seismic stations, located tens or hundreds of kilometers from each other [7]. Such a network has a length of thousands of kilometers and the registration capabilities of the network are determined by the number of seismic stations in it. To clarify the local seismicity in the preparation of construction sites, as well as to monitor the activity of volcanoes, small networks of three to four seismic stations located hundreds of meters or several kilometers apart are used. This allows you to directly determine the local seismicity, as well as to detect the activity of the volcano before the eruption and determine the parameters of the forthcoming eruption (emission height, forecast of lava and pyroclastic flows, as well as volcanic mud flows - "lahars" [8,9]. In the region, there is no widespread coverage of both power supply networks and cellular and wired networks. In 2017, a comprehensive expedition to Matua was organized, in which he took part tie author of the article [10]. A network of four autonomous seismic stations was deployed, which worked for one month. Measurement data were processed and information on the local seismicity of the island and adjacent territories was obtained. The network of seismic stations of Matua allowed to complement the existing network of seismic stations of Sakhalin, Kuriles and Kamchatka [11]. Based on the experience gained by the network in a desert island and harsh climatic conditions, a concept was put forward and the structure of an autonomous network of seismic stations was developed, a search and selection of its constituent elements was carried out.

2. Network of seismic stations on Matua Island in 2017

As part of a comprehensive expedition of the 2017 Russian Geographical Society in 2017, an experimental network of field seismic stations was deployed on the island of Matua based on Delta-
03M seismic recorders [12, 13]. The purpose of the network was to determine the suitability of Delta-03 and Delta-03M seismic recorders for field conditions, register and hypocentre weak seismic events, as well as monitor the activity of the Sarychev Peak located on Matua. Installation locations of seismic stations Klyuv, Lahar, Ainu and Yurlov are shown in Figure 1.

Figure 1. Installation sites of seismic stations on Matua (Klyuv, Lahar, Ainu and Yurlov).

The choice of installation sites for seismic stations was carried out on the basis of the principle of placement of seismic stations in the tops of a convex quadrilateral, as well as the possibility of access to any of them within one day without using transport. The location at the vertices of a convex quadrilateral allows the implementation of a triangulation method for determining the hypocenters of seismic events. For the method of triangulation, three seismic stations are enough. The fourth seismic station is installed to increase reliability. Subsequently, it turned out that the GPS time synchronization system at the Ainu seismic station had a hidden defect, which excluded the data of this seismic station from triangulation processing.

Matua Island is of volcanic origin, and there are no bedrock or hard rocks, but in large quantities there are concrete constructions erected by the Japanese for various purposes: long-term firing points (bunkers), rainwater collection basins, anti-aircraft battery, artillery caponiers, machine-gun nests. For the installation of seismic sensors were used concrete pedestals of these structures. At Cape Klyuv, the
A seismic station was installed at the DOT, in Ainu Bay and at Yurlov Cape - at machine gun points, in the vicinity of the Lahara (eruption of Sarychev peak in 2009) - on the concrete edge of the basin. The machine gun point, in which a seismic station is installed in the vicinity of Cape Yurlov, is shown in Figure 2.

When installing seismic sensors, it is necessary to orient them to the cardinal points. At Matua, a magnetic anomaly is observed with a declination value from 2˚ to 10˚, with an even greater magnetic declination observed in concrete structures. Therefore, seismic sensors were installed not by a compass, but by a GPS navigator. This method was complicated by the fact that when entering the concrete structures GPS-navigator loses satellites. Therefore, the transfer of the direction into the room was carried out by geometric methods. In Figure 3 shows the location of the seismic sensor and the container with the equipment of the seismic station Klyuv.

The network of seismic stations on Matua Island lasted from June 13 to 29, 2017. The seismic stations were powered by batteries with a capacity of 65 ampere-hours, which lasted for 6 days of operation of the seismic station based on a Delta-03 type seismic recorder. It was found that the station, equipped with a more modern seismometer "Delta-03M" (Ainu), consumes significantly less electricity. PCMCIA flash drives of the station with a capacity of 16 GB at a sampling rate of 100 Hz were enough for 80 days, which significantly exceeded the period of operation of the seismic stations during the expedition. According to the experience of previous expeditions to the Kuril Islands, it was known that wild animals (foxes) spoil the field equipment, gnaw the insulation of cables. To protect the cables from animals, a special composition has been developed based on sharp-smelling components. During the operation of seismic stations, traces of foxes were repeatedly found on them, but the equipment and cables were not damaged. The air humidity on the island of Matua is so high that after a week the metal objects left outside the container showed signs of corrosion, and the cardboard packaging was damp even in the rooms. Seismic recorders and seismic sensors were
designed for similar conditions and at the time of the removal of corrosion they did not have. The Lahar seismic station worked in the most severe climatic conditions, in the open installation variant: on the edge of the basin of the rainwater collection system, among the thicket of the woodland on the edge of the snowfield at the foot of the volcano. In Figure 4 shows the Lahar seismic station at the time of dismantling on June 30, 2017. The snow mass is visible in the basin.

The island’s road network is currently limited. A light armored multipurpose armored personnel carrier MT-LB was used to move around the island for mounting / dismounting and replacement of seismic station batteries. To control the work, to read the data, it was not necessary to involve transport, since it was possible on foot to visit all seismic stations except the Klyuv. The shortest way to the station Klyuv passed along the coast through rocks and large boulders, and a good road passed through mountainous terrain through serpentine and thicket of dense forest, therefore the trip to it always took almost the whole day. In Figure 5 shows the dismantling process of the Ainu seismic station.
During the operation of the seismic stations, they were periodically monitored for their condition, backing up data and replacing batteries. For measurement management and data exchange, the Samsung NC-110 netbook was used, which showed low power consumption (up to 6 hours of battery life) and good performance with a small mass (about 1 kg). Records of seismic recorders were viewed to control their suitability for subsequent processing after returning from the expedition. In Figure 6 shows the seismic control program in the waveform viewing mode. Channels 1 and 2 are the oscillation velocities in the horizontal plane along the x and y axes (transverse, or “S-waves”). Channel 3 - the oscillation velocity along the vertical axis (longitudinal or “P-waves”).

After the end of the expedition, the measurement data of the seismic stations were transferred to the seismology laboratory of the Institute of Marine Geology and Geophysics of the Far Eastern Branch of the Russian Academy of Sciences for processing. Data processing was performed using data from the network of seismic stations on the islands of Paramushir and Iturup of the Sakhalin branch of the Geophysical Survey of the Russian Academy of Sciences (Yuzhno-Sakhalinsk, Russia). It turned out
that about 70% of the seismic events in the Middle Kuriles were recorded exclusively using the network of seismic stations of Matua. An updated map of the Kuril zone earthquakes in June 2017 was compiled, which is shown in Figure 7 [11].

![Figure 7. Updated map of the Kuril zone earthquakes in June 2017.](image)

The location of the stations on the island makes it possible to monitor the state of the Sarychev Peak volcano. It is possible to accurately determine the hypocenter and magnitude of weak seismic events associated with the state of the volcano. On the island of Matua, the construction of the base of the Armed Forces of Russia is underway, so it is necessary to monitor the state of the Sarychev Peak volcano in order to predict natural hazards such as ash emissions, mudflows (lahars), pyroclastic emissions. Sarychev Peak is an active volcano, the last eruption was in 2009, and a particularly strong eruption was in 1946, when all people had to be evacuated from Matua Island [14].

3. Actuality and elements of the autonomous network of seismic stations of Matua Island

As already mentioned, about 70% of earthquakes in the Middle Kurile region are recorded only by the seismic stations of Matua. Volcano Peak Sarycheva is a potential hazard to personnel working on the island [11]. Therefore, the tasks of monitoring the seismic situation in the zone of the Middle Kuriles, as well as monitoring the state of the Sarychev Peak volcano are relevant. The network of seismic stations should be autonomous both from the point of view of its non-volatility, and from the point of view of the possibility of operating outside the coverage area of a cellular network. The construction of such a network of seismic stations is possible through the use of unconventional renewable energy sources, the organization of the network via radio, as well as the transmission of data via satellite channel. Moreover, the operation of an autonomous network of seismic stations should not require human presence, but at present all seismic stations operate without the need for an operator.

The intellectual core of the seismic station is a computer. Taking into account the low required performance, it is advisable to use so-called single-board computers, which are now widely distributed in many embedded systems. These computers do not use active cooling, so they do not contain moving parts. This solution will ensure minimum power consumption with maximum reliability [15, 16].
The measuring core of the seismic station is a seismic recorder paired with a seismic sensor. The choice of seismic recorders on the Russian market is now small in principle, but given the narrow specifics of this equipment, this is natural. In June 2017, the Delta-03 seismic recorder manufactured by Logis Geotech (Russia) with the SPV-3K seismic sensors from the same company was used at the seismic stations of Matua island. At present, NDAS-8226 seismic recorders with SME-6111 molar seismometers from R-Sensors have shown good performance [17]. It is also possible to use our own original technical solutions [18].

To collect measurement data of various seismic stations serves as a radio modem. According to the developed network concept, one of the four seismic stations serves as a server, communicates with a data collection and processing center via satellite communication. The remaining three stations are “slave” operating in the local radio network of the VHF band. The use of the VHF band was made possible because all four stations are in line of sight. There are ready-made devices on the market for solving such problems [19].

To transmit data to the data receiving and processing center, a satellite modem is required, which is part of the equipment of one of the seismic stations. The presence of computers in the composition of seismic stations allows for automatic primary data processing in order not to transmit information about background noise over a satellite channel [20]. The transfer of information is carried out either by external request, or upon the occurrence of a seismic event (for example, an earthquake). The best place to install a satellite modem is the Klyuv seismic station, since there is a spacious room (bunker) that can be used to accommodate more equipment. In addition, the location of the “leading” seismic station on Cape Klyuv allows you to control it visually directly from the anchorage in the Dvoynaya Bay. The shore of the bay allows disembarking from watercraft, therefore, if repair is necessary, it is possible to land in this bay. The view from the Klyuv Cape to the Dvoynaya Bay is shown in Figure 8. In the foreground are thickets of hard-walked «elfin wood», on the left you can see the Toporkovy island, on the far right you can see Cape Yurlov. The kiellichter ship, tugboat and topographic ship that were part of the expedition of 2017 are visible in the bay. On the water visible waves from the strong wind in the direction of the Dvoynaya Bay.

![Figure 8. The view from the Klyuv Cape to the Dvoynaya Bay.](image-url)
Matua Island is characterized by a constant wind of great power [21]. This allows the use of wind turbines to power seismic stations. Solar panels are inefficient due to the small number of sunny days per year. The selected equipment of wind power plants allows to provide power to seismic stations in the year-round mode without the need to connect to centralized power supply networks, which are simply not available on Matua Island [22, 23].

Batteries are the "weak point" of autonomous systems, as they are sensitive to operating conditions, temperature, and discharge and charge modes. The most frequent reason for the need to repair autonomous systems and tools is the failure of the battery. Different types of batteries have different advantages and disadvantages, but the common feature of all batteries is the presence of deficiencies. Lead-acid batteries do not tolerate deep discharge. Nickel-metal hydride and nickel-cadmium batteries have a "memory effect" and a tendency to imbalance. Lithium-ion batteries do not work at low temperatures. Silver-zinc batteries are extremely expensive. [24]

Instead of batteries of seismic stations, it is advisable to use ionistor blocks. An ionistor is a new generation device designed for storing electrical energy [25, 26]. By its properties, the ionistor resembles a capacitor, but it has an huge electrical capacity of thousands of farads. Therefore, ionistors are called supercapacitors. Ionistor perfectly transfers up to 100 thousand charge-discharge cycles without loss of capacity and is not afraid of deep discharge and low temperatures (up to -20 °C). The voltage on the ionistor is proportional to the charge, therefore, as the ionistor is discharged, the voltage on it decreases. This problem was solved by applying pulse-width modulation (PWM) upconverters. The Ionistor energy storage device together with the PWM converter ensures a constant voltage on the load, that is, on the equipment of the seismic station. [27]

4. Conclusion
The proposed concept of building a network of seismic stations allows you to create data collection points that are independent of the availability of power supply systems and cellular networks. This will expand the network of seismic stations in the Far East and establish seismic stations in remote and deserted areas.

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