

Registration and spectral analysis of waveforms of 10.24.2019 earthquake in the Caucasus using the new IGES-006 seismic sensor

*J. K. Karapetyan¹, A. S. Gasparyan¹,
S. R. Shakhparonyan¹, R. K. Karapetyan¹*

Institute of Geophysics and Engineering Seismology after
A. Nazarov NAS RA, Gyumri, Armenia

Abstract. The paper considers the application possibility of the new IGES-006 seismic sensor for monitoring tasks. The sensor is developed at the Institute of Geophysics and Engineering Seismology after A. Nazarov of the National Academy of Sciences of Armenia. The IGES-006 sensor can be used both as part of various seismic monitoring systems and for solving special engineering problems. The sensor prototype has successfully passed laboratory and field tests, including the seismic monitoring mode. To assess the possibility of using the IGES-006 sensor as an import-substituting scientific device, it was compared with the Russian SPV-3K sensor, which is quite similar in parameters. A comparative analysis of seismic signals recorded using IGES-006 and SPV-3K sensors in the time and frequency domains have been carried out. The comparison results indicate the prospects for mass production of IGES-006.

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Introduction

Instrumental observations are an integral part of geophysical research [*Dzeboev et al.*, 2019; *Ismail-Zadeh et al.*, 2020; *Karapetyan et al.*, 2020]. To upgrade the monitoring systems and to solve fundamental problems of seismology, engineering seismology, and earthquake engineering, it is necessary to constantly improve the quality of instrumental observations. This requires the development and implementation of new generation instruments. First of all, this concerns the development of seismic sensors, their dynamic, and frequency ranges.

For many years, the team of the Institute of Geophysics and Engineering Seismology after A. Nazarov of the National Academy of Sciences of Armenia (IGES NAS RA) has been actively working on the development of modern geophysical instruments for solving scientific and special engineering problems. One of the traditional directions for the Institute is the development of seismometric equipment, including those based on the SM-3 seismic sensors. The main results of these developments over the past 30 years are reflected in publications [*Sarkgsyan*, 2014, 2010; *Karapetyan and Gasparyan*, 2018].

Currently, the problem of improving the quality of

mass seismological observations is solved by equipping observational seismometric and engineering-seismometric stations with devices of a new generation. This makes it possible to perform high-level monitoring (registration and analysis of earthquakes, micro-earthquakes, etc.) of urbanized areas, especially critical facilities, buildings, and structures.

It has to be noted that the models of seismological instruments, developed and manufactured before the 1990s, can no longer satisfy the increased requirements. In recent years, the elemental base of electronic components has been updated, new opportunities for information technologies and improved designs have appeared, including the mechanical elements of the suspension for vertical and horizontal seismometers [*Rykov*, 1992, 2002; *Sidorin*, 2018; *Vasilev et al.*, 2016; *Karapetyan*, 2018a, 2018b; *Karapetyan and Karapetyan*, 2019].

All this gives rise to works in IGES NAS RA on the modernization of existing seismometers and the creation of domestic, much cheaper unique seismic devices with relatively simple designs and capable of replacing expensive foreign analogs.

Short Period Seismic Sensor

In 1975 V. A. Tokmakov developed the SM-3 seismic receiver, which is still widely used in both seismological and engineering research. The seismic receiver SM-3 is designed to convert mechanical vibrations into vibrations of electric current. It can be used to measure vertical and horizontal vibrations in various systems. SM-3 has a smooth natural frequency adjustment up to 0.5 Hz and a temperature compensator for the vertical version of the seismometer. It can be easily readjusted from vertical to horizontal and vice versa [*Tokmakov*, 1975]. There is evidence from some US sources about the use of the SM-3 seismic receiver as a standard for calibrating seismic instruments [*Mackey et al.*, 2013].

The main disadvantages of the SM-3 seismic receiver are: heavy weight, large overall dimensions, difficulties in adjustment during operation, instability of the zero position, the low attenuation coefficient of natural vibrations of the pendulum.

The authors of this work summarized the experience of the best domestic developments, analyzed the achievements and problems of modern seismometry, and proposed the most economically and quickly feasible way of creating a new seismic receiver – the mod-

ernization of the SM-3. The purpose of the modernization is to reduce weight, increase the attenuation coefficient, simplify the design, improve performance, and ensure the stability of the zero position of the device.

The weight of the SM-3 is 7.7 kg. It contains more than 30 high-precision parts, that require the manufacture by a highly skilled workforce and special tooling. In turn, the upgraded version of the device, which was named IGES-006, weighs less than 1 kg, contains less than 10 parts, which do not require any special high-precision production.

When operating in the field conditions the following inconveniences arise with SM-3: to set up the device, one must open the cover, uncage, set the zero position of the pendulum and close the cover again. After closing the cover, in a while the temperature inside the device changes, which leads to a change in the zero position of the pendulum. In this regard, there is a need for repeated re-adjustment. When used in a network of multiple sensors, the setup process becomes laborious, tedious, and time-consuming. The upgraded IGES-006 sensor has improved performance. The release and the setting of the pendulum to the zero position are carried out without opening the cover of the device.



Figure 1. The general view of the seismic sensor IGES-006.

The developed seismometer is designed to upgrade existing national networks of seismological and engineering-seismometric observations, both in Armenia and abroad [Karapetyan, 2017, 2018c; Karapetyan *et al.*, 2020]. The general view of the seismic sensor IGES-006 is shown in Figure 1.

Figure 2 shows the structural diagram of the IGES-006 seismic receiver. The sensor is located in a housing in which an oscillating pendulum with inertial mass

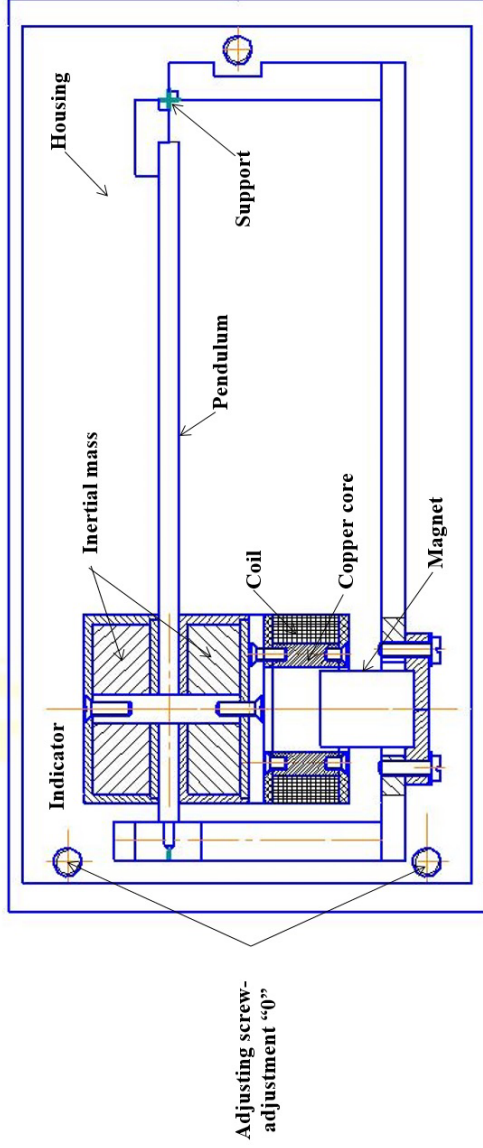


Figure 2. Structural diagram of the seismic sensor IGES-006.

and a coil on the same axis with the inertial mass are installed. The sensor also has a neodymium magnet located on the housing coaxially with the coil and a copper core. Structurally, the seismic receiver is an inertial pendulum with its own period adjustable up to 3 sec Figure 2.

The seismic receiver is housed in a waterproof stainless-steel case with an output connector for connection to the logger. Three versions of the seismic receiver have been developed: with periods of natural oscillations of the pendulum 1.0, 1.5, and 2.5 sec. The attenuation coefficient of the pendulums is critical. The pendulum is set to zero position without opening the cover of the device. The inertial masses and the coil are balanced relative to the swing axis of the pendulum, which makes it possible to abandon the use of spiral springs. This, in turn, eliminates the temperature instability of the seismic sensor.

With a change in temperature for SM-3 seismometer, the pendulum changes its position of equilibrium, since when the temperature changes, the spring stiffness mainly changes due to a change in its elastic properties [*Savarensky and Kirnos*, 1995].

To determine the thermal stability of the SM-3 seismic receiver and the upgraded IGES-006 sensor, joint

laboratory temperature tests were carried out. At a temperature of $+50^{\circ}\text{C}$, the displacement of the SM-3 pendulum was 10 mm, while for IGES-006 the displacement of the pendulum was not observed. There is no need to use springs to set the pendulum to zero position.

The vertical sensor has an electromechanical drive to maintain the zero position of the pendulum. The drive is powered by a built-in Li-Ion battery, which ensures continuous operation of the device for at least one year.

The implemented technologies provide a cheaper alternative for the development of mass seismic observation facilities in Armenia in comparison with the existing foreign programs for the modernization of seismic monitoring networks. The main characteristics of the IGES-006 seismometer are shown in Table 1.

Measurement Results in Seismic Monitoring Mode

IGES-006 successfully passed laboratory and field tests and was recommended for test use in monitoring mode, in particular, at stations of regional seismic networks in areas with high seismic hazard.

Table 1. The main characteristics of the IGES-006 seismometer

No.	Specifications	Dimension	Value
1	Working frequency range	Hz	0.3–50
2	Irregularity of the amplitude-frequency response in the operating frequency range	dB	3
3	Nominal conversion factor	in s/m	30
4	Attenuation	–	1
5	Seismic receiver dimensions (one component)	mm	$70 \times 70 \times 60$
6	Weight of one seismic receiver, no more than	kg	1
7	Control unit dimensions	mm	$205 \times 150 \times 70$
8	Control unit weight	kg	1.1
9	Working temperature range	°C	–60 ... + 40
10	Relative humidity at an ambient temperature of 25°C	–	80

For testing in monitoring mode from September 30 to October 2, 2019, in the Republic of North Ossetia-Alania (Russian Federation), the IGES-006 sensor was installed at two seismic stations with digital control units: in Vladikavkaz and in the village of Karmadon Figure 3. The stations are part of the seismic network of the Geophysical Institute VSC RAS.

After the installation of the IGES-006 seismic receivers in the Western Caucasus region on October 24, 2019, an earthquake occurred with the following focal parameters: 2019-10-24 15:41:41, latitude 43.12, longitude 44.57, depth 15 km, mb: 3.4/4. The earthquake was recorded by the SPV-3K and IGES-006 seismic receivers installed at the “Vladikavkaz” and “Karmadon” stations Figure 4].

Figure 5 and Figure 6 show the records of the horizontal component X and the corresponding spectra of the waveforms of the earthquake of October 24, 2019, recorded by the IGES-006 (green) and SPV-3K (black) seismic receivers.

Comparative analysis shows that there is a good correspondence of waveforms and spectra of records obtained using IGES-006 and SPV-3K sensors. However, the first arrival of the waveforms is identified more clearly on the IGES-006 record (Figure 5 and Figure 6).



Figure 3. Seismic stations “Karmadon” (on the left) and “Vladikavkaz” (on the right), where sensors IGES-006 and SPV-3K were installed.

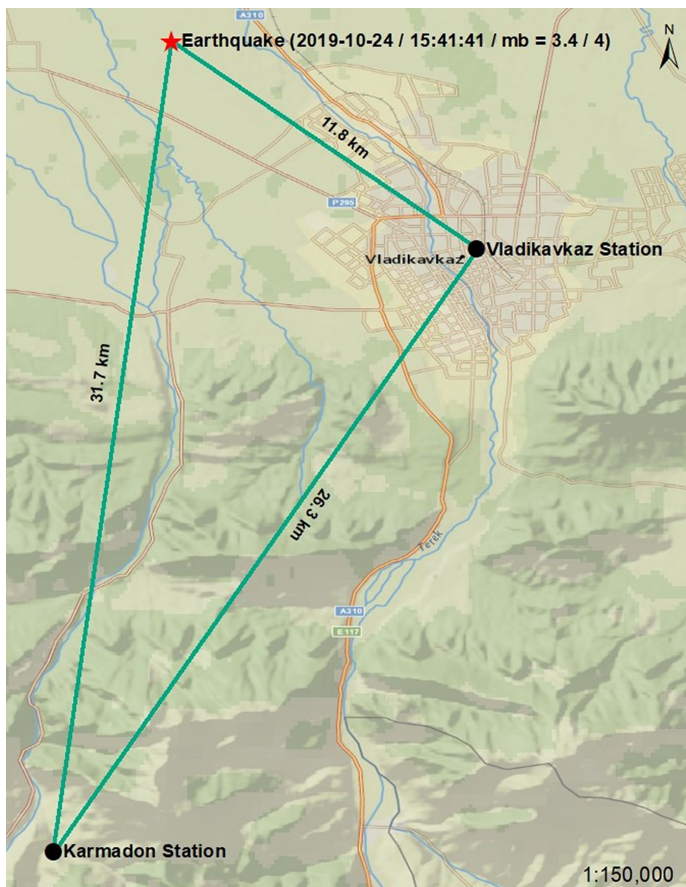


Figure 4. Location of seismic stations “Karmadon” and “Vladikavkaz” in relation to the epicenter of the earthquake of October 24, 2019.

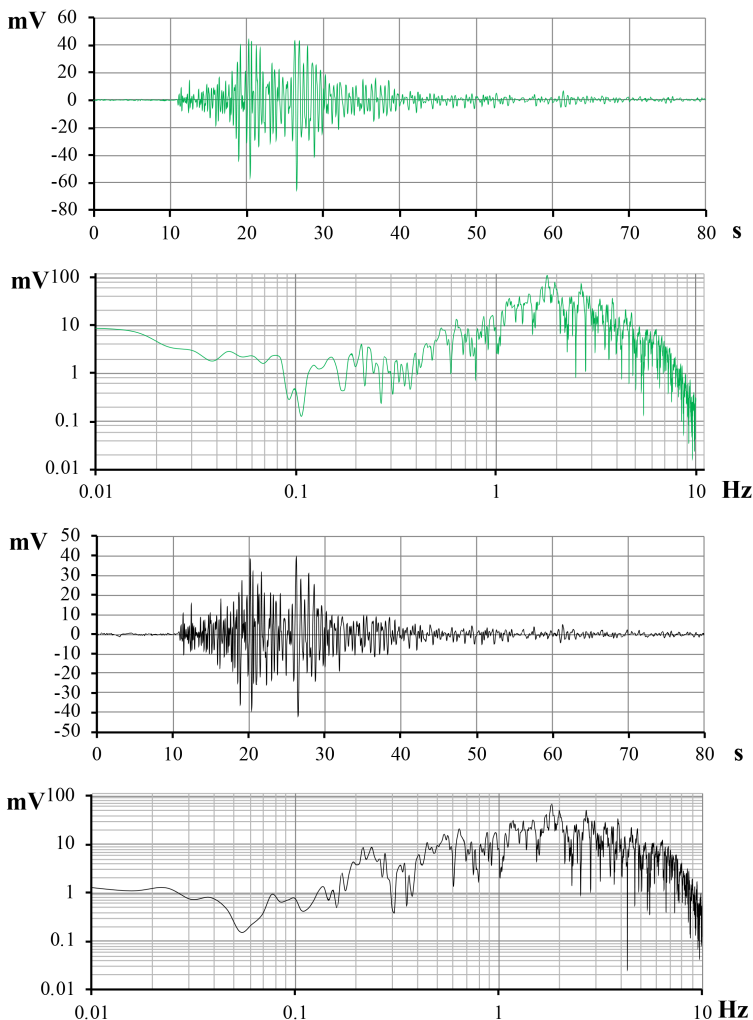


Figure 5. Records of the X horizontal component of the earthquake of October 24, 2019, of the “Karmadon” station and the corresponding waveform spectra: green – IGES-006, black – SPV-3K.

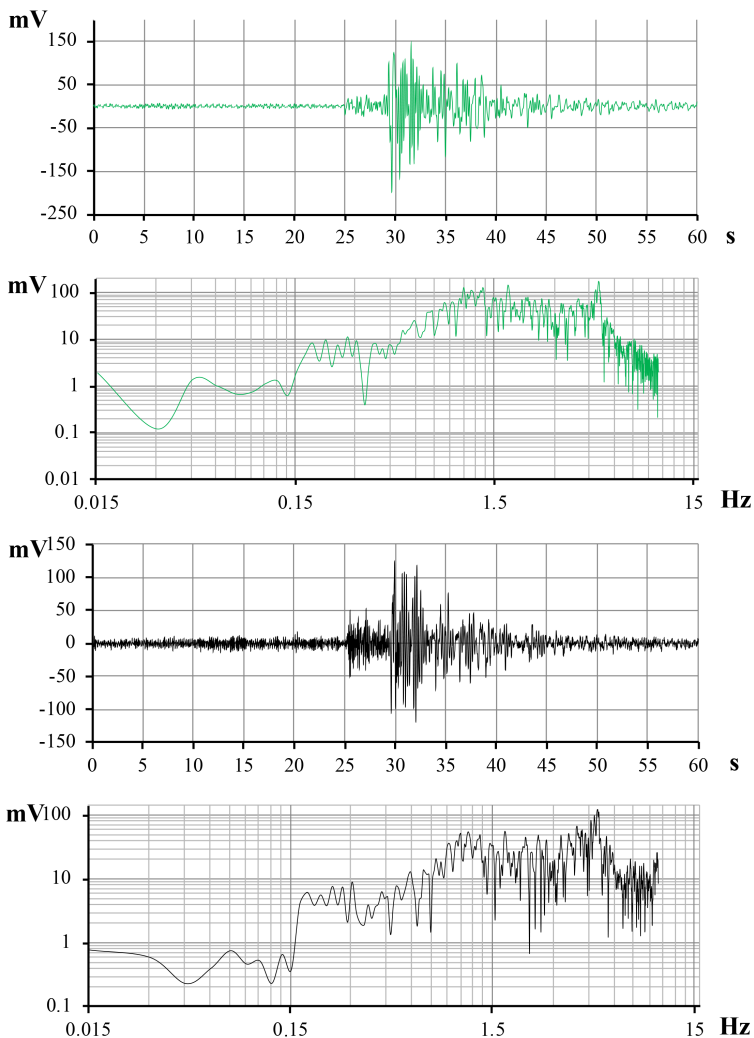


Figure 6. Records of the X horizontal component of the earthquake of October 24, 2019, at the “Vladikavkaz” station and the corresponding wave-form spectra: green – IGES-006, black – SPV-3K.

The SPV-3K record shows increased (by about a factor of 2) background amplitude, which can be interpreted as instrumental noise (Figure 6).

Spectral analysis of records from the IGES-006 and SPV-3K sensors shows that, in the general case, the values of the prevailing periods coincide: $T = 0.37$ sec and $T = 0.55$ sec (Figure 5 – records of the earthquake by the station “Karmadon” and the corresponding spectra of waveforms). The values of the prevailing periods on the spectra of the IGES-006 and SPV-3K sensors coincide $T = 0.20$ sec and $T = 0.57$ sec (Figure 6 – records of the earthquake obtained by the station “Vladikavkaz” and the corresponding spectra of waveforms). However, there are some differences when comparing spectral densities (Figure 5 and Figure 6).

To demonstrate the correspondence of the earthquake records in Figure 7 and Figure 8 are presented comparisons of waveforms and corresponding spectra for the IGES-006 and SPV-3K seismometers at the “Karmadon” and “Vladikavkaz” stations.

Comparative analysis shows a good agreement of waveforms in both time and amplitude. However, there are some differences in the amplitude values, which, are apparently associated with different sensitivity of the IGES-006 and SPV-3K seismic receivers (Figure 7 and

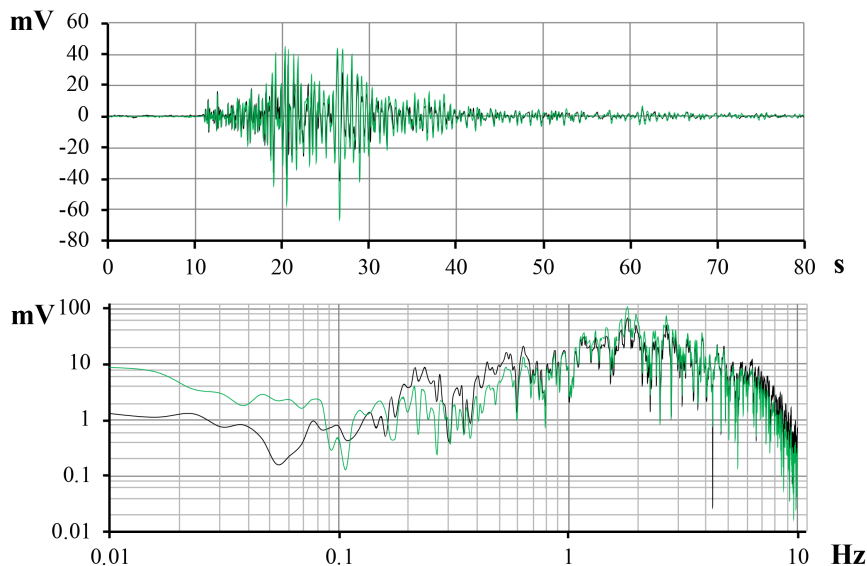


Figure 7. Comparison of waveforms and spectra of records for the IGES-006 and SPV-3K seismometers at the “Karmadon” station.

Figure 8).

Table 2 shows the quantitative parameters (Peak Ground Velocity-PGV) of ground vibrations (records from the IGES-006 and SPV-3K seismometers), and also some integral (Velocity Spectrum Intensity-VSI, Cumulative Absolute Velocity-CAV) parameters are calculated as more stable energy parameters of seismic impact [Karapetyan, 2013; Grigoryan and Karapetyan, 2008].

Table 2. Parameters of ground vibration and seismic impact

“Karmadon”		“Vladikavkaz”		
	IGES-006	SPV-3K	IGES-006	SPV-3K
T¹	0.5554	0.5554	0.5699	0.5749
ω₁	1.8005	1.8005	1.7548	1.7395
T²	0.3745	0.3745	0.1998	0.2004
ω₂	2.6703	2.6703	5.0049	4.9896
PGV	66.9337	42.1953	201.9528	126.5613
ASI	59.4310	45.5519	171.7707	117.4456
CAV	365159.0086	278974.9051	706490.0571	531466.8229

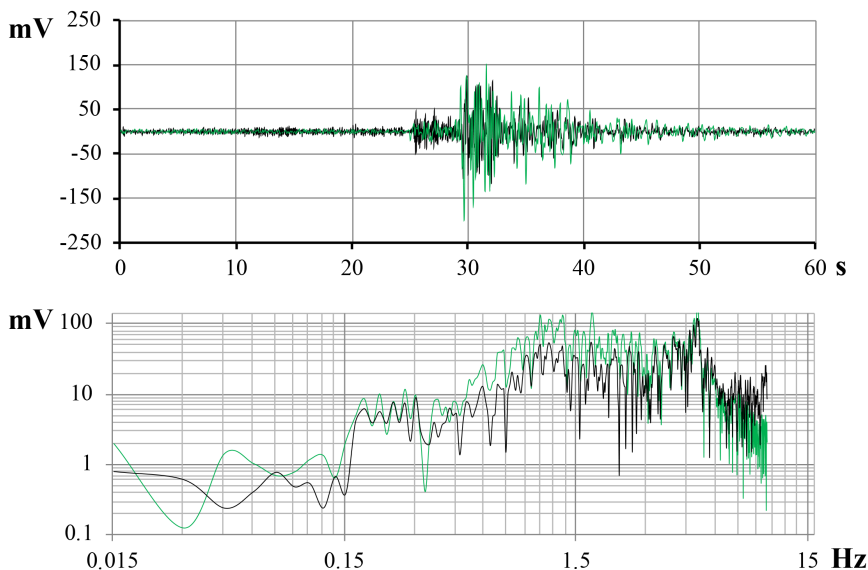


Figure 8. Comparison of waveforms and spectra of records for the IGES-006 and SPV-3K seismometers at the “Vladikavkaz” station.

Comparative assessment of parameters in Table 2 shows that the maximum amplitudes on the IGES-006 records are 1.59 times greater than those on the SPV-3K instrument records (“Karmadon” and “Vladikavkaz” stations). This is apparently due to the different sensitivities of the devices.

At a distance of 31.7 km from the epicenter (Figure 4), the maximum amplitude on the IGES-006 record of the “Karmadon” station is 66.9 mV, and on the

IGES-006 record of the “Vladikavkaz” station is 201.9 mV that is 3 times less. The ratio of the epicentral distances for the “Vladikavkaz” and “Karmadon” stations is 2.7. The ratio of the values of the integral parameters, in particular CAV, is 1.9. The same values were obtained by comparing the corresponding parameters on the SPV-3K record of the “Karmadon” and “Vladikavkaz” stations. The ratio of the values of the integral parameters, in particular ASI, which describes the spectral composition, calculated from the SPV-3K and IGES-006 records, are 2.6 and 2.9, respectively. In other words, when the distance changes 2.7 times, the maximum amplitude changes 3 times, and the CAV parameter changes 1.9 times. This is more reasonable since CAV takes into account not only the waveform, but also the recording duration and, in fact, represents an energy parameter and behaves more stable.

Table 2 shows that in all cases the spectra show a dominant period of 0.56 sec. Apparently, this is the main characteristic period of this earthquake.

Conclusion

A small-sized sensor for monitoring systems has been developed that meets the highest modern requirements. This is a short-period seismic sensor with periods of

natural oscillations of the pendulum of 1.0, 1.5, and 2.5 sec. Its frequency response corresponds to a velocimeter and has the flattest section in the 0.3–50 Hz band. The model of the seismic sensor has successfully passed laboratory and field tests, including in the seismic monitoring mode.

Conducted joint tests of portable seismic sensors IGES-006 and SPV-3K indicate a good agreement for characteristics of the seismic process, recorded independently by both devices.

The studies conducted make it possible to confirm that small-sized short-period geophones can replace large and more expensive sensors.

The small-sized short-period seismometer IGES-006 developed by the authors is designed to upgrade existing national seismological and engineering seismometric observations, regional and local geodynamic studies.

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