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MICROSEISMIC VIBRATION MEASUREMENTS WITH *Vp/Vs* ASSESSMENT AT THE CHARTAK RESERVOIR DAM

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ABSTRACT

This paper presents the results of a study of microseismical vibrations and the possibility of estimating the *Vp/Vs* ratio, as well as the physical parameters of dam conditions, using the Chartak Reservoir as an example. The Nakamura method was used to obtain the ratios of the spectra of the horizontal components of microseismical vibrations to the spectrum of their vertical components (H/V ratios). Determining the *H/V* ratio and *Kg* revealed that the seismic instability coefficient *Kg* at the dam crest does not exceed 17.8. It was also found that an inclined seismic impact increases the amplitude amplification factor of the Chartak Reservoir dam vibrations.

Key words: dam, microseismical vibrations, longitudinal and transverse waves, shear modulus, compression modulus.

ÇARTAK SU ANBARI BƏNDİNDƏ VP/VS NİSBƏTİNİN QİYMƏTLƏNDİRİLMƏSİ İLƏ MİKROSEYSMİK VİBRASİYA ÖLÇMƏLƏRİ

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ANNOTASİYA

Bu məqalədə Çartak Su Anbarı nümunəsində mikroseysmik titrəyişlərin tədqiqinin nəticələri, həmçinin Vp/Vs nisbətinin və bəndin vəziyyətinin fiziki parametrlərinin qiymətləndirilməsi imkanları təqdim olunur. Mikroseysmik titrəyişlərin üfüqi komponentlərinin spektrlərinin onların şaquli komponentlərinin spektrinə nisbətlərinin (H/V nisbətləri) əldə edilməsi üçün Nakamura üsulundan istifadə edilmişdir. H/V nisbətinin və Kg parametrinin müəyyən edilməsi nəticəsində məlum olmuşdur ki, bəndin krestində seysmik qeyri-sabitlik əmsalı Kg 17,8-dən artıq deyil. Həmçinin müəyyən edilmişdir ki, maili seysmik təsir Çartak Su Anbarı bəndinin titrəyişlərinin amplituda güclənmə əmsalını artırır.

МИКРОСЕЙСМИЧЕСКИЕ ВИБРАЦИОННЫЕ ИЗМЕРЕНИЯ С ОЦЕНКОЙ ОТНОШЕНИЯ VP/VS НА ПЛОТИНЕ ЧАРТАКСКОГО ВОДОХРАНИЛИЩА

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АННОТАЦИЯ

В работе представлены результаты изучение микросейсмических колебаний и возможности оценки *Vp/Vs*, а также физических параметров состояния плотин на примере Чартакского водохранилища. Для получения отношений спектров горизонтальных компонент микросейсмических колебаний к спектру их вертикальной компоненты (*H/V* отношений) использовано метод Накамуры. Определение соотношения *H/V* и *Kg* показало, что,

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коэффициент сейсмической неустойчивости *Kg* на гребне плотины не превышает значения 17,8. Выявлено, что наклонное сейсмическое воздействие увеличивает коэффициент усиления амплитуды колебаний плотины Чартакского водохранилища.

Ключевые слова: плотина, микросейсмические колебания, продольные и поперечные волны, модуль сдвига, модуль сжатия.

Introduction

The physical parameters of a medium-sized reservoir dam are assessed by recording microseismical vibrations within its body (*Khamidov*, 2020; *Rodrigues, Paula and oth.*, 2021; *Yusupov, Mamarozikov, and oth.*, 2025). Studying changes in the natural vibrations of dams and embankments of similar reservoirs in Uzbekistan allows us to study physical changes in their structural structure. It is known that microseismical monitoring is implemented using two main methods: passive microseismical and interferometric, based on the analysis of seismic noise in the environment (*Yusupov, Mamarozikov, and oth.*, 2025; *Khamidov, Artikov, and oth.* 2022) Although interferometry is not always available in practice, it can relate the rigidity modulus and specific gravity of an object. Passive microseismical monitoring also provides valuable information about the structure of dams. Passive microseismical surveys allow reservoir owners to monitor seismic activity within their territories and in adjacent areas (*Rodrigues, Paula and oth.*, 2021; *Yusupov, Mamarozikov, and oth.*, 2025). This is valuable for analyzing historical seismic data, identifying potentially induced seismicity, and for regional monitoring of subsurface geology and hydrogeology.

Due to the significant impact of water level changes in this regularly used reservoir, areas of hydrostatic pressure may form within the rock-fill dam. Uneven kinematic displacements within the dam body, in turn, depend on the conditions under which its physical and mechanical parameters change under the influence of natural seismic forces. In this case, the physical parameters of the dam can be determined from changes in longitudinal (*Vp*) and shear (*Vs*) seismic waves.

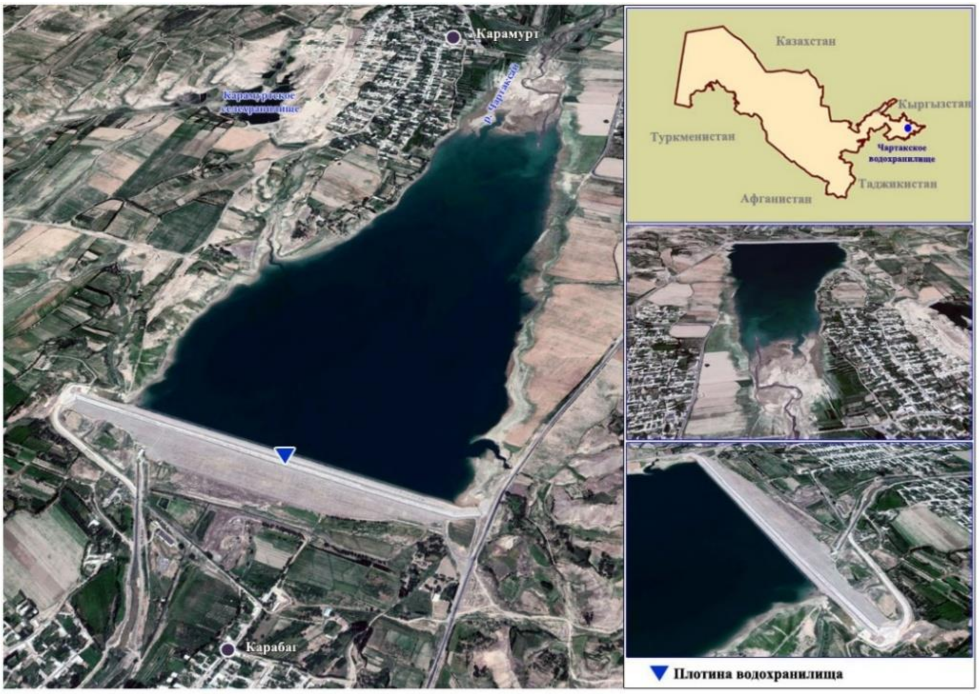


Figure. 1. Location of the Chartak reservoir according to (Website of the MWR RUz, 14.10.2025)

In recent years, in order to increase the efficiency of seismic research in the Chartak reservoir zone, local seismic monitoring of micro-vibrations has been organized in order to assess the natural frequencies of both the dam and the coastal slopes.

The aim of the research is to study microseismical vibrations and the possibility of assessing *Vp/Vs*, as well as physical parameters of the state of dams using the Chartak reservoir as an example.

Currently, the concept of "microseismical observations" encompasses a whole range of technologies based on the analysis of waves of various origins and types (emission, man-made signals, surface waves, etc.). It is important that the recorded wave field can be processed in parallel using different methods, based on different components of microseisms, to obtain fundamentally different information about the environment. The method of analyzing the state of an earth dam allows one to take into account the design features of the structure, piecewise heterogeneous physical and mechanical characteristics of the soils of both the structure and its foundation (*Yusupov, Mamarozikov, and oth.*, 2025; *Khamidov, Artikov, and oth.* 2022).

The Chartak Reservoir is located in the Namangan Region of the Republic of Uzbekistan, 20 km northwest of Namangan. Phase I was commissioned in 1971, and Phase VI in 2013. The Chartaksay River is the source of water supply. The dam is 1,448 meters long and 37 meters high. It is located in the zone of 8-point earthquake intensity (Fig. 1) (*Website of the MWR RUz*, 14.10.2025).

Tectonically, the Chartak Reservoir is located within a belt of anticlinal uplifts of Neogene-Quaternary, and possibly earlier, age, marking a zone of major disturbances in the Paleozoic basement. This zone can be identified with a major fault zone, exhibiting all the characteristics of a marginal fault [6], or a so-called flexural-fault zone (*Sadykov, Nurmatov and oth.*; 2021; *Rebetsky, Ibragimova and oth.*, 2020). The dam site is located north of the most intense disturbances in the southern part of the zone (the Namangan anticline) and west of the most complexly constructed and actively developing eastern part of this zone.

Research methodology

To obtain analytical information, expeditionary studies were conducted to determine the seismic and natural frequencies of vibrations of the Chartak Reservoir dam and shore slopes. The H/V ratio represents the transfer function of the soil cross-section across the entire thickness of the relatively cohesive geological material of the engineering foundation, representing an analogue of the amplitude-frequency characteristic (*Khamidov, Ibragimov and oth.*, 2020; *Nakamura*, 1989).

Figure. 2. Location of registration points in the dam body Chartak Reservoir

Observations are performed by a single three-component station without loss of quality of the resulting data. This allows for the rapid and detailed resolution of the tasks set during engineering and seismological studies.

The measurements were limited to recording microseisms at 40-minute intervals with a step size of 25 to 100 meters along the crest and berms of the Chartak Reservoir dam. The locations of ten microseismical recording points within the Chartak Reservoir dam are shown in Figure 2.

Table 1.

Recording point coordinates and calculated parameters obtained from microseismical measurements

№ MP	**Chartak**				
	Coordinates		***f₀***	**HVSR**	***Kg***
	N	**E**			
1	41,17664	71,80263	0,68	4,48	29,5
2	41,17646	71,80412	0,71	3,49	17,2
3	41,17635	71,80550	1,01	3,43	11,6
4	41,17617	71,80694	1,13	4,48	17,8
5	41,17604	71,80879	1,11	3,36	10,2
6	41,17589	71,81025	1,09	5,04	23,3
7	41,17576	71,81162	0,93	4,62	23,0
8	41,17554	71,81402	0,92	3,71	15,0
9	41,17532	71,81644	1,09	4,71	20,4
Hydro Post 10 1 km from the dam	41,16937	71,80931	0,89	4,25	20,3

The following software environment was used to process the records: GEOPSY, (*H/V* Nakamura's ratio), Waves. (*Nakamura,* 1989). Three-component digital seismometers (velocimeters) with a built-in recorder CMG-6TDE manufactured by Guralp, UK, were used to record microseisms.

By processing microseismical records, the spectral amplitudes of the two horizontal components (*N-S* and *E-W*) and the vertical component are calculated. The results are presented as the ratio of the horizontal component (*H*) to the vertical component (*V*) as a function of frequency (*f*):

$$[H/V](f)=\left[\frac{S_{NS}^{2}(f)+S_{EW}^{2}(f)}{2S_{V}^{2}(f)}\right]^{1/2} \tag{1}$$

Next, the dominant frequencies (or periods) and relative amplitude levels of oscillations are determined using the *H/V(f)* curve (1).

Estimates of natural oscillations from multi-profile seism metric surveys in dams were determined by calculating the relative change in oscillation intensity from $\delta_i=A_{ma\,(i)}/A_{ma}$, where *i* is the sequential number of the measurement points. Calculations of the thickness of the layer from coarse-grained to fine-grained rocks were performed in reservoirs using the following empirical equations: $h=156 \cdot f_0 - 1{,}08$, where *h* is the thickness of the fill rock layer, *fo* is the resonant frequency of each part of the debris massif. To determine the velocity of transverse waves *Vs*, the expression $T = 4h/Vs$ was used; where *T* is the resonant period for each type of rock mass, *h* is the thickness of each part of the rock, and *Vs* is the velocity of transverse waves. To eliminate random impulse noise, the spectra were calculated using preliminary filtering (*Khamidov, Artikov, and oth.* 2022; *Khamidov, Ibragimov and oth.*, 2020).

Research results

During the first measurement cycle, a dam body natural frequency profile was compiled with precise data on the recording points. Changes in the natural frequencies at certain recording points can be used to assess the degree of water load on the dam body or changes in the dam body's condition.

Table 1 presents the calculated parameters obtained from microseismical measurements, including Fo (the soil resonance frequency), the HVSR transmission coefficient, and *Kg* (the seismic instability coefficient) based on the coordinates of the measurement points.

Table 2 shows the values of shear (*Vs*) and longitudinal (*Vp*) waves and the volume density (ρ) calculated and determined by microseismical surveys at the specified points of the Chartak Reservoir dam.

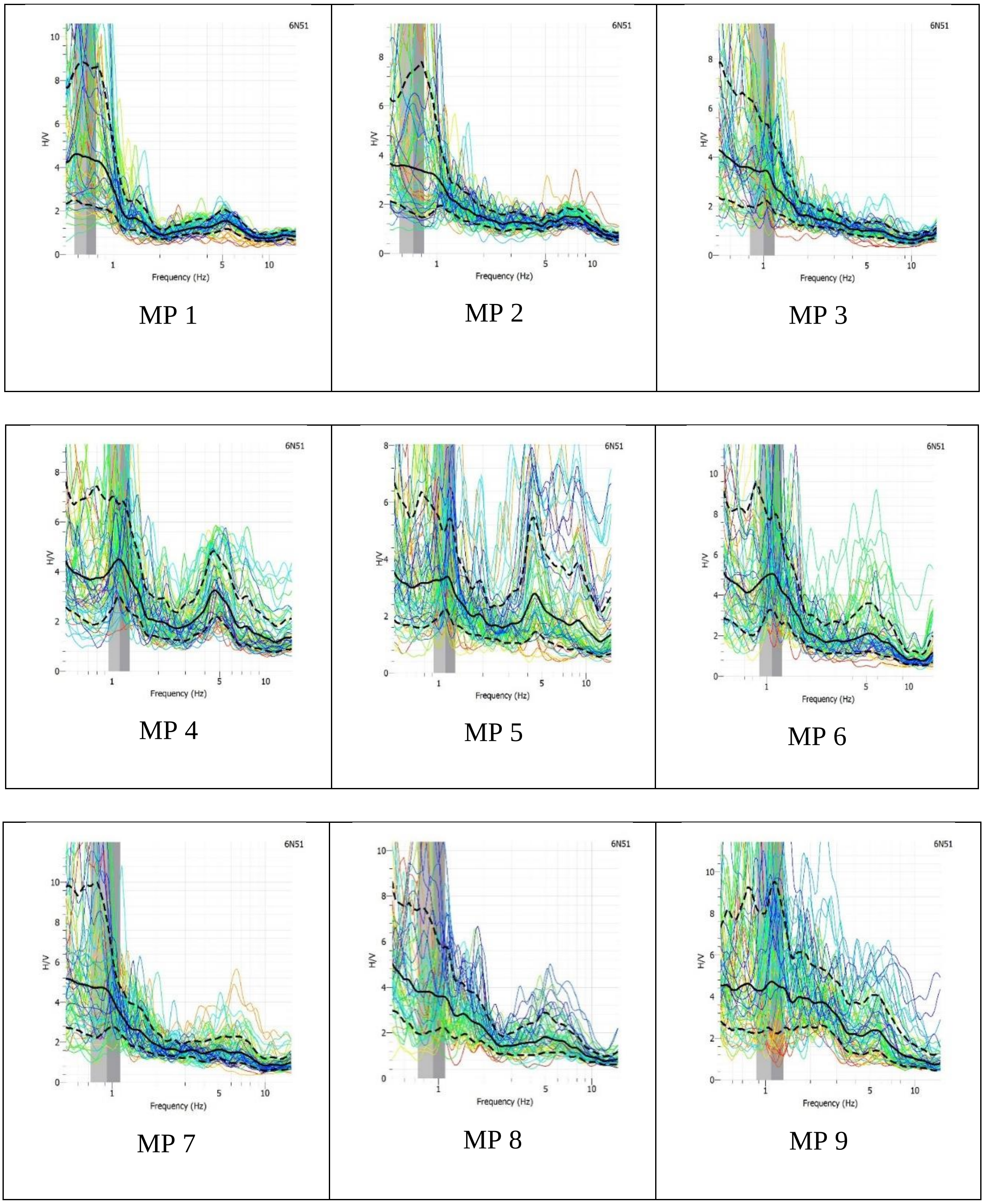
Figure 3 below shows the points (MP measurement points according to Figure 2) where instrumental seismometric measurements were conducted in the Chartak Reservoir dam body.

Table 2.

Changes in physical parameters along the Chartak Reservoir dam body

H (m)	**V_p**	**V_s**	**ρ (kg/m^3)**	**μ**	**λ**	**υ**	**E**	**Vp/Vs**
	m/s			**(GPa)**	**(GPa)**		**(GPa)**	
3,5	253	151	1500	0,03	0,03	0,22	0,08	1,68
7	315	195	1814	0,07	0,04	0,19	0,16	1,62
49	397	257	2571	0,17	0,07	0,14	0,39	1,54
3	302	145	1490	0,03	0,07	0,35	0,08	2,08
6	315	185	1841	0,06	0,06	0,24	0,16	1,70
49	470	278	2586	0,20	0,17	0,23	0,49	1,69
5	242	150	1538	0,03	0,02	0,19	0,08	1,61
11	301	180	1844	0,06	0,05	0,22	0,15	1,67
45	408	243	2512	0,15	0,12	0,23	0,36	1,68
3	491	150	1587	0,04	0,31	0,45	0,10	3,27
14	624	300	1831	0,16	0,38	0,35	0,44	2,08
44	1132	517	2420	0,65	1,81	0,37	1,77	2,19
3	344	147	1522	0,03	0,11	0,39	0,09	2,34
6	413	219	1851	0,09	0,14	0,30	0,23	1,89
46	503	305	2565	0,24	0,17	0,21	0,58	1,65
4	244	142	1545	0,03	0,03	0,24	0,08	1,72
7	495	148	1953	0,04	0,39	0,45	0,12	3,34
50	525	293	2565	0,22	0,27	0,27	0,56	1,79
3	246	150	1542	0,03	0,02	0,20	0,08	1,64
8	400	170	1943	0,06	0,20	0,39	0,16	2,35
50	500	300	2501	0,23	0,18	0,22	0,55	1,67
3	243	150	1530	0,03	0,02	0,19	0,08	1,62
8	494	187	1903	0,07	0,33	0,42	0,19	2,64
50	507	307	2500	0,24	0,17	0,21	0,57	1,65
6	245	144	1574	0,03	0,03	0,24	0,08	1,70
9	500	215	1967	0,09	0,31	0,39	0,25	2,33
50	759	384	2516	0,37	0,71	0,33	0,99	1,98

Fig. 3 shows the frequency distribution of microseismical signals at recording points in the dam body.



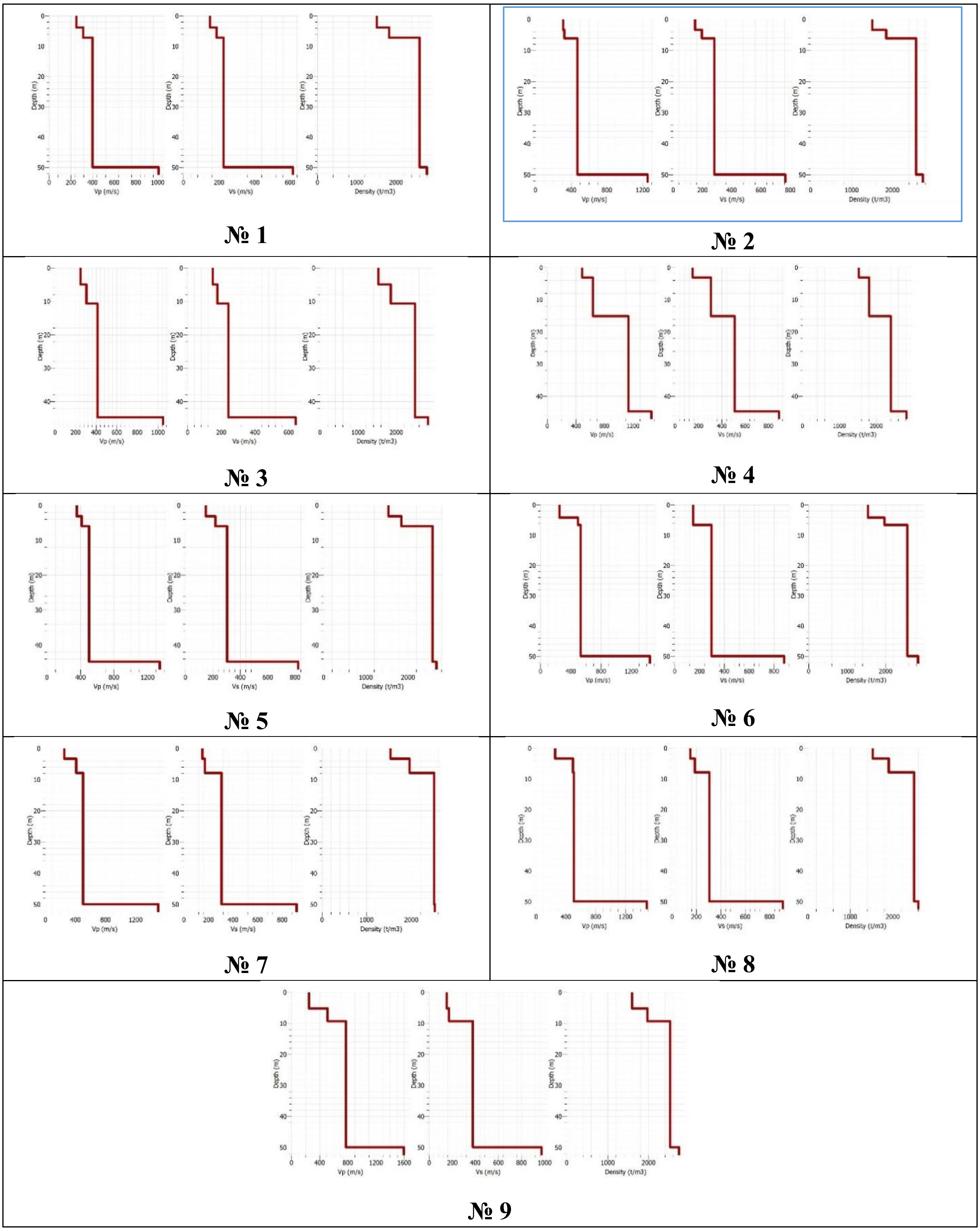
MP 1 MP 2 MP 3

MP 4 MP 5 MP 6

MP 7 MP 8 MP 9

Figure. 3. Frequency distribution of microseismic signals at 1 recording point according to Fig. 2

Fig. 4 shows the changes in the depth of transverse (*Vs*) and longitudinal (*Vp*) waves and the bulk density (ρ) determined on the body of the Chartak reservoir dam.



№ 1

№ 2

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№ 6

№ 7

№ 8

№ 9

Figure. 4. Graph of changes in the depth of transverse (Vs) and longitudinal (Vp) waves and bulk density (ρ), determined on the body of the Chartak reservoir dam

The calculations were based on microseismical recordings at nine measuring points (MP) on the Chartak Reservoir dam and one point 1 km away from the dam. Figure 4 below shows a graph of the variation in shear (*Vs*) and longitudinal (*Vp*) wave depth and bulk density determined for the Chartak Reservoir dam body.

Interpretation of seismic data obtained from the reservoir dam using *P*- and *S*-wave velocities and rock density resulted in the determination of the velocity ratio *K*, shear modulus μ, elastic constant λ, Poisson's ratio ν,Young's modulus E and bulk density. The figures and calculation results clearly demonstrate differences in the spectral and amplitude components of microseismical vibrations. The natural vibrations of the dam body at various points consist of an ensemble of frequencies (vibration modes) that depend on the physical state of the structure.

The obtained experimental data were processed using standard methods, including: spectral calculation and analysis of natural microseisms; construction of *H/V* ratio spectra; modeling of one-dimensional vertical soil sections in the shear wave velocity format and obtaining geotechnical parameters of the thickness of layered soils. Data processing was carried out using the Geopsy program (www.geopsy.org) (*Software EU: GEOPSY, appeal October* 2025).

These parameters have the following characteristics: the velocity ratio $K = Vp/Vs$ is used to determine the ratio of the velocities of longitudinal and shear waves. The average value of the *K* coefficient for strong earthquakes is taken to be 1.73. Since the wave parameters of microseismic vibrations are small, this coefficient can be significant. The shear modulus was determined using the following formula: $\mu = V_S^2 \cdot \rho$, where ρ (g/cm3) is the density of the fill rock. The distribution of the compressive modulus across the dam body is predominantly high at the base (river flow zone), and when analyzing the data obtained for the dam, it was noted that the shear modulus increases threefold (0.23–0.64 GPa) toward the central part of the dam.

Conclusion

Microseismical vibration measurements and *Vp/Vs* ratio assessments at the Chartak Reservoir dam revealed that oblique seismic action increases the amplitude amplification factor of the Chartak Reservoir dam's vibrations. The maximum relative up-down displacement in these dams decreased with increasing V_P wave incidence angle, while the relative displacement increased with increasing V_S wave incidence angle. This suggests that the maximum principal stresses at the dam's nodal points initially increased and then decreased with increasing V_P -wave incidence angle and gradually decreased with increasing V_S wave incidence angle. A frequency profile was compiled for the Chartak Reservoir dam's support points. An assessment of the seismic instability coefficient of the Chartak Reservoir dam, based on in-situ measurements of vibration frequencies and the H/V ratio and *Kg*, revealed that the seismic instability coefficient *Kg* at the dam crest does not exceed 17.8. No man-made conditions affecting the seismic instability coefficient *Kg* at the Chartak Reservoir dam crest were identified.

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