

Defectoscope for monitoring of a concrete timbering of underground constructions

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Abstract. The purpose of work is development of a defectoscope for nondestructive identification of spaces in rock mass on border with a concrete timbering. The principle of operation of the device consists in the analysis of parameters of vibration of a timbering after drawing blow to it. The difference from the known developments consists in contactless reception of an acoustic signal with use of the microphone. Parameters of vibration of a timbering are determined under various conditions of its contact with rock mass. Initial requirements for development of a defectoscope are experimentally defined. Its block diagram is submitted and principal specifications are given. Data on approbation of the equipment in hydraulic engineering constructions are given.

1 Introduction

The concrete timbering is the most widespread at construction of underground constructions. In Ukraine it is widely used for fastening of vertical shafts in mines on coal mining, salts and uranium [1-3]. In case of unstable rocks is applied as well to maintenance of horizontal capital workings. Its application in hydrotechnical tunnels of big section [4] is effective. The term of operation of a timbering is decades.

Reliability of a timbering worsens at arrangement of development in soft rocks. Emergence of spaces behind a concrete cover is the main reason. They are caused by influence of aquifers. Violation of dense contact of a cover with the rock mass leads to uneven distribution of tension on its surface. Manifestation of this process is emergence of cracks in concrete. Further they become sources of filtration (Fig. 1). The reliability of the design is gradually reduced.

Effective method for prevention of deformations of a timbering is cementation of spaces. But it demands their preliminary identification and delimitation. Performance of inspection is often connected with the working use termination for the intended purpose. Thereof, the main requirement is the high efficiency of control. It can be reached only with use of nondestructive methods.

Now in world practice for identification of spaces behind a concrete cover two methods were widely adopted: high-frequency georadar-location [5, 6] and low-frequency ultrasonic tomography [7, 8].

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Fig. 1. Cracks with filtration in a concrete timbering of gallery of the Dnistrovskiy hydroelectric power station.

Development of the specified methods became possible only in the last 20 years. It is caused by need of use of the portable computer equipment which allows operation in adverse environmental conditions. Data on some means of nondestructive control are presented in Table 1.

Table 1. Means of nondestructive control for identification of spaces behind a concrete cover of underground constructions.

Type equipments	Model	Firm, company	Country
High-frequency georadar	Proceq GPR Live	Proceq	Switzerland
	OKO-3	Logis-Geotech	Russia
	SIR-20	GSSI	USA
	NOGGIN-1000	Sensor & Software	Canada
	RAMAC/GPR	Mala GeoScience.	Sweden
	Gepard GPR 3D	OKM	Germany
	VIY3-700	Transient Technologies	Ukraine
	Probe-12e	Radar Systems	Latvia
Low-frequency ultrasonic tomograph	Pundit 200 Pulse Echo	Proceq	Switzerland
	A1040 mira	AKS	Russia
	TC200	Time Group	China

Use of the mentioned types of the equipment has some restrictions. It demands direct contact with a surface of a concrete cover. It causes sharp decline in production of control at inspection of workings of big section. At inspection of vertical shafts direct access to certain sites of their surface is in general impossible. The equipment has high cost and is

intended for work with personnel of high qualification. The obtained primary data often demand additional processing in cameral conditions.

In parallel, since the end of last century, the method of vibroacoustic control was developed for the solution of similar tasks [9, 10]. Its essence consists in pointed impact excitation of the site of a design and the subsequent analysis of its free oscillations. For reception of oscillations contact seismometers or piezoelectric transducers use. Advantage of a method is the possibility of arrangement of the activator and receiver of oscillations on sticks. Their length can reach up to 4 m. It allows to survey workings up to 6 m high without use of elevators.

In Ukraine and abroad there is no large-lot industrial production of the equipment of vibroacoustic control for identification of the hidden spaces. Developments which were issued small parties are known. Most of them are spectrum analyzers of a single signal. Data on some devices are presented in Table 2.

Table 2. Means of vibroacoustic control for identification of the hidden spaces.

Model	Informative parameter of oscillations	Organization, company	Country
«ISK-ISH»	spectral structure	Institute of Geotechnical Mechanics of NAS of Ukraine	Ukraine
«Dikon»	duration		
«Resonans»	spectral structure	GEOFIZPROGNOZ	Russia
«Poisk –MGI»	spectral structure	Moscow State Mining University	Russia
Vibroset	spectral structure	Holding triad	Russia
SVAN-946	spectral structure	SVANTEK	Poland

Use of means of vibroacoustic control significantly expands opportunities for nondestructive control of the "concrete timbering-the massif" system. Their common fault is need of stable acoustic contact of the receiver of vibration with the surface of concrete. There was a need of development of the device with remote registration of vibration. This publication is devoted to the solution of the mentioned task.

2 Methods

In natural conditions the possibility of use of the microphone for remote registration of oscillations of a concrete cover after shock was investigated. Researches were carried out on various underground hydrotechnical objects and also in conveyor developments of the iron ore enterprise - public joint-stock company "ArselorMittal Kryvyi Rih" and in the uranium mine "Nova" of the company "Skhid-Ruda". For excitation of oscillations the special impact device was used. It represents a cylindrical steel shock head with a diameter of 30 mm which is fixed on a wooden stick. The stick consists of separate sections. Their total length reaches 4 m. The contact surface of a head is executed by spherical. For increase in superficial hardness it is tempered. In the experiment, a set of heads of various lengths, having a mass of 0.3, 0.8 and 1.5 kg, was used.

For registration of oscillations used a portable digital dictaphone. The distance from a shock point to a dictaphone made from 2 to 3 m. For reduction of acoustic hindrances record was carried out by idle processing equipment.

Initial processing of the results involves the selection of signals with low noise. In the future, perform their spectral analysis. To determine the duration of the oscillatory process, the oscillogram of each signal is studied.

3 Results and discussion

Reliable assessment of parameters of a sound signal requires the high relation of a useful signal to the level of noise. At the first stage of experiments it was necessary to establish such opportunity in real conditions of production. The analysis of experimental material defined requirements for receiving a high-quality signal. The most important is the lack of acoustic hindrances. The second condition is distribution of functions of the operator and assistant. The assistant strikes blow and the motionless operator keeps record of acoustic impulses. The third condition consists in the correct striking a blow. Its direction has to be perpendicular to a surface of a concrete structure. The blow has to be sharp. Necessary energy of blow depends on thickness of a cover and a condition of a surface. The speed of the movement of a impact head accepted in the ergonomic plan is from 1.5 to 2 m/s. Experimentally established requirements to its mass are presented in Table 3.

Table 3. Requirements to the impact device.

Thickness of concrete, m	Surface condition	Mass of a head, kg
0.2 – 0.5	smooth	0.3
	with a loose coating to 5 mm	0.8
0.5 – 0.8	smooth	0.8
	with a loose coating to 5 mm	1.5
0.8 – 1.0	smooth	1.5
	with a loose coating to 5 mm	-

For computer processing of a signal only high-quality recordings were used. The task – to find essential distinctions of parameters of oscillations at dense contact of a cover with the massif and at its absence was set. Distinctions are visible already when comparing oscillograms. In Figure 2 the form of free oscillations of a concrete slab 0.3 m thick at dense contact with the massif is presented, and in Figure 3 - with a cavity.

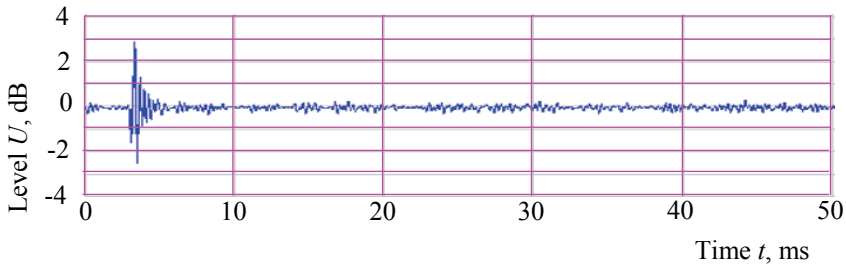


Fig. 2. Oscillogram of free oscillations of the site of a plate at dense contact with rock mass.

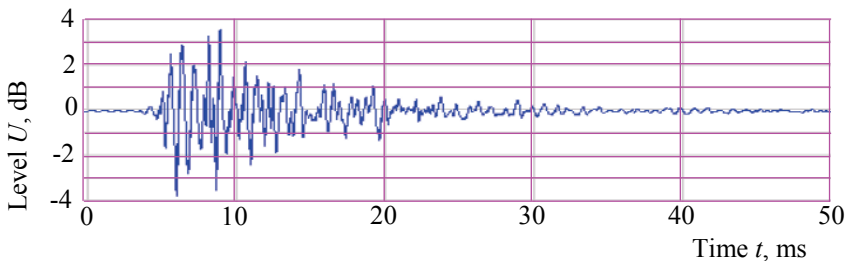


Fig. 3. Oscillogram of free oscillations of the site of a plate in the presence of a cavity.

The analysis of the provided oscillograms shows that in the presence of a cavity duration of oscillatory process significantly increases.

Differs as well spectral structure of oscillations for a plate 0.3 m thick at dense contact with rock mass the spectrum is illustrated by Figure 4.

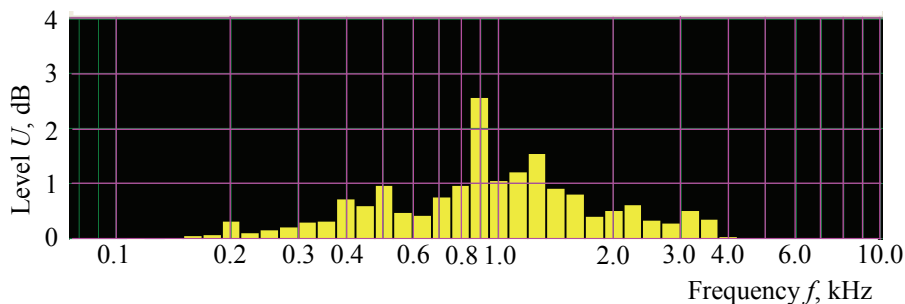


Fig. 4. A spectrum of free oscillations of the site of a plate at dense contact with the massif.

In the presence of a cavity in the massif on contact with a plate of the similar sizes occurs shifts of a maximum of spectral density towards low frequencies. At the same time resonant properties of a plate are distinctly shown. As an illustration serves Figure 5.

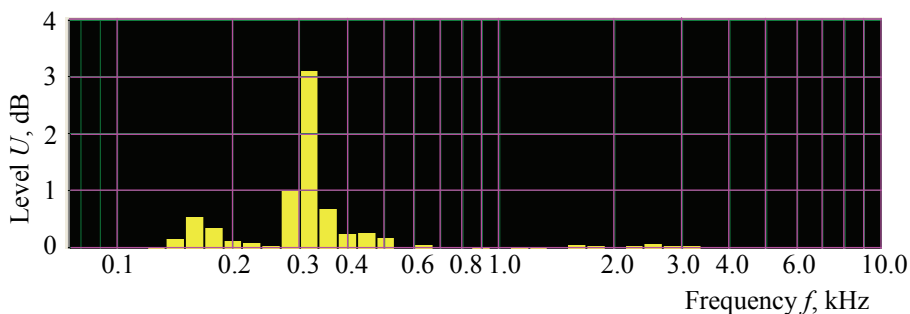


Fig. 5. A spectrum of free oscillations of the Site of a Plate in the presence of a cavity in the massif.

At dense contact of a plate with the massif influence of its sizes on parameters of free fluctuations is insignificant. In the presence of a cavity with increase in thickness of a plate numerical characteristics of oscillatory process approach option of dense contact. For an illustration Table 4 serves.

Table 4. Numerical characteristics of damped oscillations of a plate.

Oscillation process parameter	Plate thickness in the presence of a cavity, m			Dense contact with the massif
	0.3	0.5	0.9	
Maximum of spectral density, kHz	0.3	0.6	0.8	0.9
Duration to level 0.1 A_{max} , ms	24.5	6.8	3.6	2.5
Time of a relaxation, ms	11.2	3.3	1.7	1.3
The number of oscillations during a relaxation	23	11	6	4

When developing the control device as informative parameter the number of oscillations during a relaxation was chosen. It is explained by simplicity of measurement of this parameter. Taking into account results of researches basic data for development are defined. They are presented in Table 5.

Table 5. Basic data for development of control devices "coverivg - the massif" systems.

Parameter	Dimension	Value
Bandwidth of an analog part	kHz	0.1 – 1.5
Time of the analysis of a signal	ms	100
Range of calculation of number of oscillations	-	0 - 999
Duration of results of indication	s	5

Under production conditions it is impossible to provide the low level of acoustic hindrances. Researches showed that synchronization of processing of a signal with the blow moment is necessary for steady operation of the equipment with use of the microphone. It is executed by use of a piezoelement which has mechanical contact with a shock head. For signal transmission of synchronization to the electronic block the flexible screened cable is used.

Use of the microphone for registration of free fluctuations of a design with synchronization of the moment of blow is realized in the defectoscope DVSH-2. Its block diagram is submitted in Figure 6.

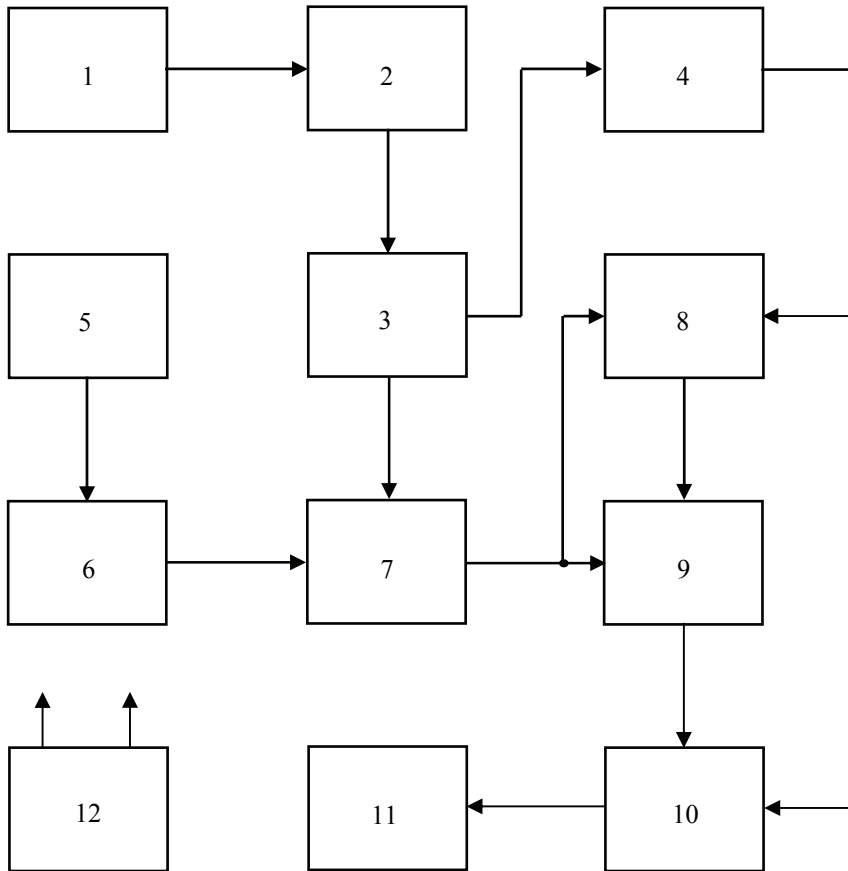


Fig. 6. Block diagram of the defectoscope: 1 - piezoelectric sensor, 2 – first comparator, 3 – first waiting univibrator, 4 – second waiting univibrator, 5 – microphone, 6 – selective amplifier, 7 – key, 8 – peak detector, 9 – second comparator, 10 – counter, 11 – numeric indicator, 12 – power supply.

Operation of the device happens as follows.

At striking a blow on concrete in piezoelectric sensor 1 there is a single impulse. The first comparator 2 compares the current value of a signal of the piezoelectric sensor to the threshold tension which considerably exceeds the level of noise. In case of excess of a signal at the output of the comparator the short rectangular impulse is formed. On its front there is a start of the first waiting univibrator 3. Duration of an impulse defines time of the analysis of a signal. On its hind front launch of the second waiting univibrator 4. Impulse duration from its exit defines time of indication of results of control. The entrance signal from microphone 5 amplifies in amplifier 6 with the set bandwidth. The key 7 opens only for the period of the analysis of a signal. Peak detector 8 remembers the maximum value of a signal U_{\max} in an analog form. The second comparator 9 compares the current value of a signal to threshold U_2 level. U_2 level size in e ($e = 2.71828\dots$) times is less than U_{\max} value. At the output of the comparator rectangular impulses are formed. Their formation will continue until the amplitude value of the input signal decreases by a factor of e . This time interval τ is called relaxation time.

For prevention of operation of the device at a weak signal blocking of operation of the second comparator is provided if U_2 level is less than the fixed U_1 threshold. Calculation of quantity of impulses carries out counter 10. Dumping of counter 10 and peak detector 8 into a zero state happens on the hind front of an impulse from the output of block 4. The result within several seconds is displayed by digital indicator 11. Supply 12 contains the rechargeable battery and the voltage stabilizer. It ensures functioning of all other structural elements of the device.

Structurally the defectoscope is executed in the form of two parts. The impact device contains a wooden stick with a set of interchangeable impact heads and a piezo sensor. The electronic block is located in the rectangular metal case with the cylindrical handle. In the handle elements of the rechargeable battery are located. On the opposite end of the case the ledge with the microphone is located. In non-working situation the microphone is closed by a rotary cover. The electronic block and the impact device are connected by a flexible cable.

The appearance of the defectoscope DVSH-2 is presented in Figure 7.

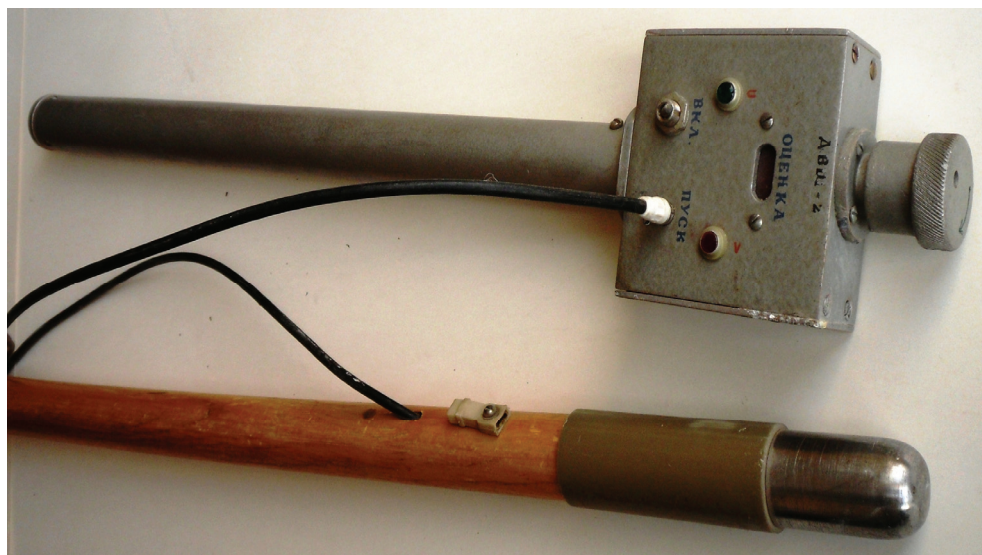


Fig. 7. Appearance of the defectoscope.

The signal processing is illustrated by the diagrams, which are shown in Figure 8.

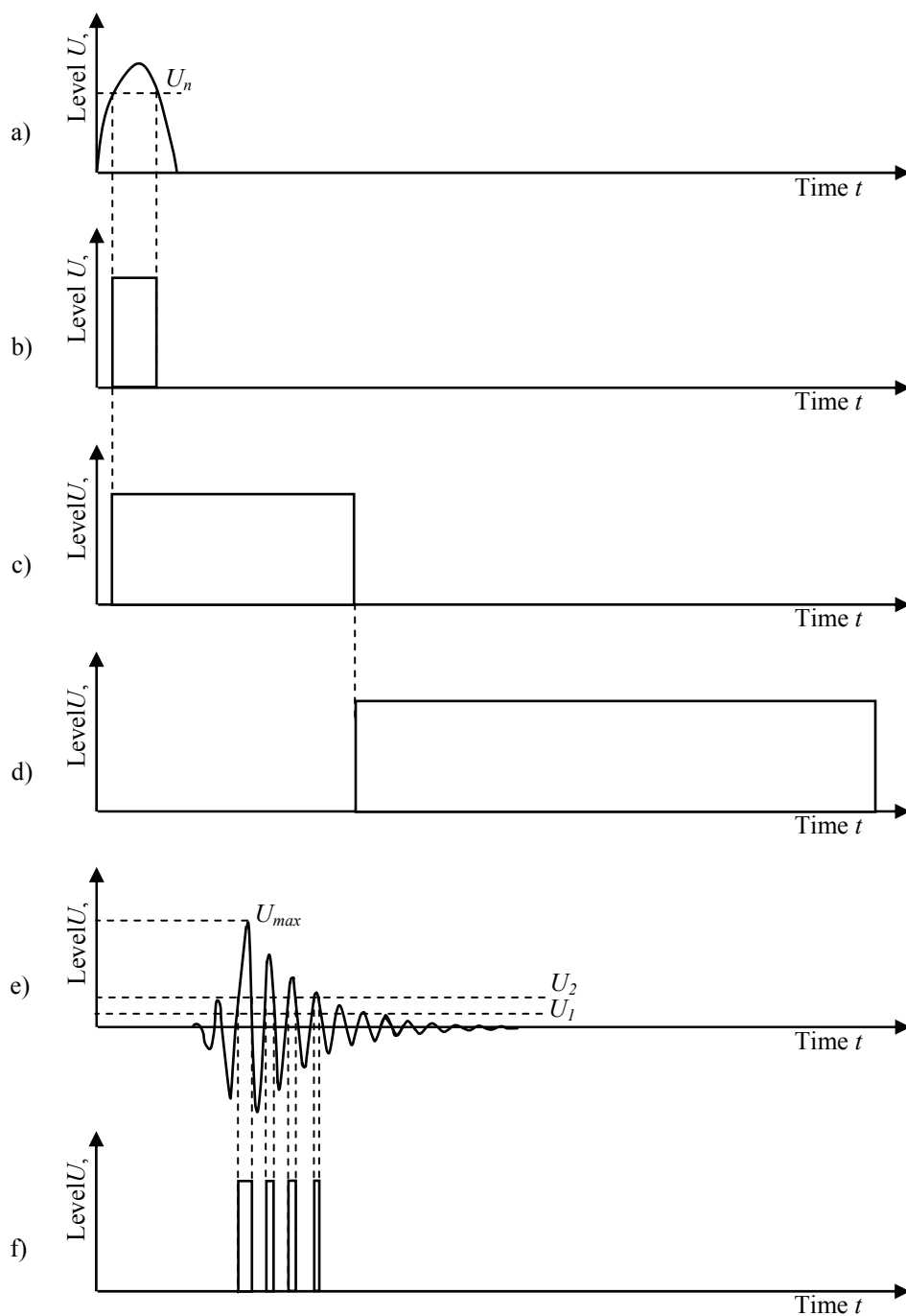


Fig. 8. Charts of operation of the defectoscope: a) – an impulse at the output of the piezoelectric sensor, b) – an impulse at the output of the first comparator, c) – an impulse at the output of the first waiting univibrator, d) – an impulse at the output of the second waiting univibrator, e) – a signal at the output of the selective amplifier, f) – impulses at the output of the second comparator.

Approbation of the defectoscope was carried out on hydraulic engineering constructions with the complicated access to a surface of a concrete cover. Diagnostics of a water throughput construction under the Inhulets main canal (Ukraine) can be an example. The appearance of a construction is presented in Figure 9.



Fig. 9. Appearance of culvert.

For identification of cavities in soil behind sidewalls and over concrete overlapping the vibroacoustic method was used. In the presence of an unstable support there was impossible use of classical option of a method with the contact receiver of vibration. The practical absence of interference led to the effective use of the defectoscope DVSH -2. By results of inspection the card of hollowness is constructed. Its fragment is given in Figure 10. Green zones of dense contact of a covering with soil, red – cavities, yellow – sites with an intermediate state are allocated.

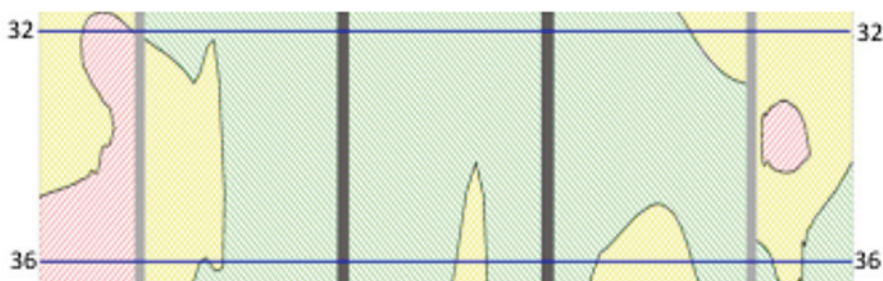


Fig. 10. Fragment of a void map behind a concrete shell.

Conclusions

According to the results of the analysis of the existing means of non-destructive testing of concrete lining, their disadvantages were established. The main one is the need for a stable contact of the sensors of the equipment with a concrete surface. The informativity of the vibro-acoustic method using a microphone for remote recording of the vibration of a section of a concrete shell was experimentally established. Justified baseline data for the development of equipment. It was found that the most informative parameter is the number of oscillations during the relaxation time of the damped oscillatory process. The result of the research was the creation of a DVCH-2 vibroacoustic flaw detector. The equipment confirmed its performance in a production environment. Its use is promising for mine workings and hydraulic structures of large cross-section, which are fixed with concrete lining.

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