MEASUREMENTS OF BRIDGE STRUCTURES USING NON-DESTRUCTIVE TESTING METHODS AND THEIR STABILITY IN WIND GUSTS

Alena Rotaru
•
All-Russian Scientific Research Institute for Civil Defence
and Emergencies of the EMERCOM of Russia
alenarotaru@mail.ru

Abstract

As bridge structures become older and older, they are subject to wear and tear due to ageing, weather conditions or environmental effects, as well as due to surprise structural modifications substantially affecting the condition of the structures. Therefore, the condition assessment of bridge structures is a must for the safety and absence of risk. The condition assessment of bridge structures is also necessary for the maintenance and repair of existing structures having been in service for more than 30 years, in order to avoid breakdowns and save human lives. This paper states the condition assessment performed with the use of various nondestructive test methods.

Keywords: bridge structures, nondestructive, test, methods, risk.

I. Introduction

Assessment of structures has been a top subject of studies in recent years. The studies in this field encompass signal processing, data management, and measurements. Topical issues of bridge structures assessment are currently defined as distributed and integrated data control and storage, data analysis and knowledge discovery, diagnostic techniques and provision of useful and reliable information to bridge owners/managers for making service and control decisions.

II. Methods

The structure condition is assessed with the use of nondestructive test methods to obtain information on the condition of the structures. This paper contains some exemplary bridge structure studies with the use of the following methods:
1) Visual inspection;
2) Ultrasonic testing;
3) Radio-wave inspection (structure penetrating radar survey);
4) Radio-wave inspection (ground penetrating radar survey);
5) Vibroacoustic inspection (dynamic testing).
Visual inspection is a nondestructive test method. Visual monitoring and field tests are used to determine the numerical indicator of damage between 0.5 and 10, as shown in Table 1.

Table 1: *Degree of damage during measuring control*

Range of measured value, mm	Measurement error, mm
Up to 0,5 inclusive	0,1
Above 0,5 to 1,0 inclusive	0,2
Above 1,0 to 1,5 inclusive	0,3
Above 1,5 to 2,5 inclusive	0,4
Above 2,5 to 4,0 inclusive	0,5
Above 4,0 to 6,0 inclusive	0,6
Above 6,0 to 10,0 inclusive	0,8
Above 10,0	1,0

The visual inspection is conducted with the use of measuring tools such as: tape measure, photo camera, calipers.

1) Visual inspection of a bridge (Pictures 1-6).

Picture 1: *View of the bridge from the right bank of the river*

Picture 2: *View of the roadway and pedestrian part of the bridge*

Picture 3: *Roadway fence construction*

Picture 4: *Internal structures of the bridge*

Picture 5: *Transition bays between bridge sections at the piers*

Picture 6: *Internal construction of bridge span adjacency to piers*

Radargrams of support 4000x3000 mm

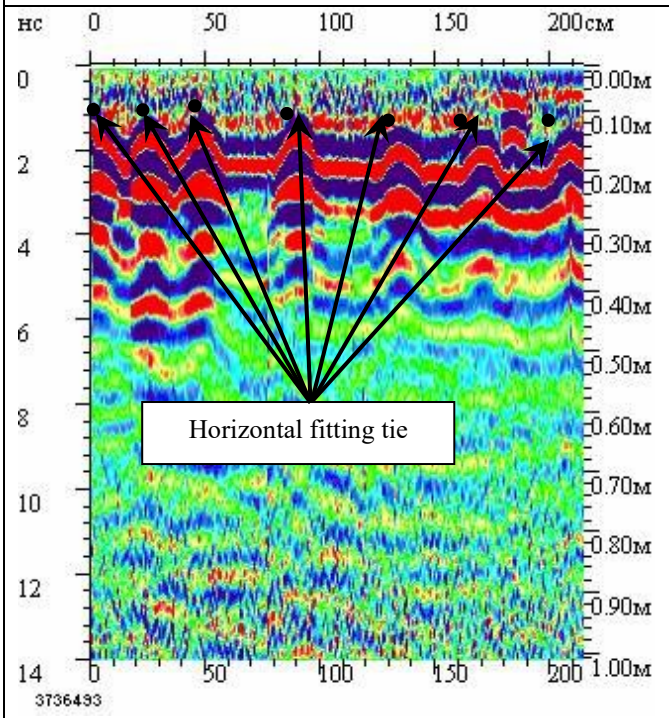
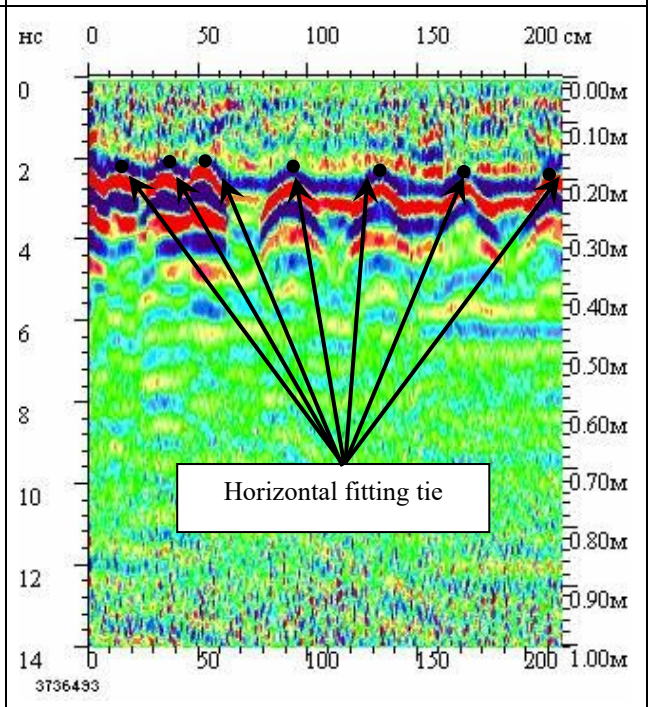
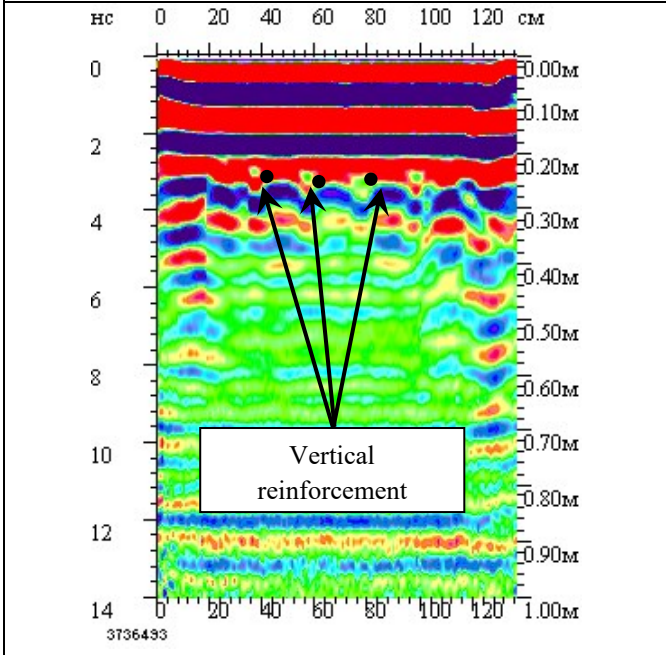
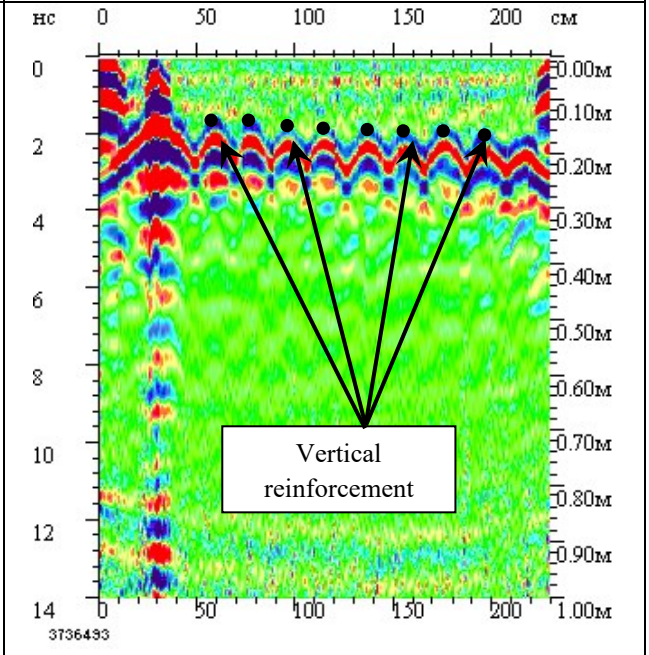
RG -1 PROFILE Z	RG-2 PROFILE Z 1
	
Horizontal reinforcement in the support is located: at the bottom of the support with a spacing of 250 mm, then with a spacing of 400 mm	
RG -3 PROFILE Y	**RG -4 PROFILE X**
	
Vertical reinforcement is spaced at 200 mm	

Figure 2: *Radargrams of support No. 9*

Finding: The scanning of the supports located on the right bank of the Volga River has yielded the following results:

Supports No. 9 – the column section is 4,000x3,000 mm, the horizontal in-column reinforcement is arranged as follows: with 200-250 mm spacing at the bottom of the column, with subsequent 400 mm spacing and the vertical reinforcement to have been arranged with 200 mm spacing. No cavities or discontinuities have been found in the concrete. Generally, the structural members of the supports are consistent with the project design.

4) Ground penetrating radar survey
The OKO-M1 penetrating radar (Picture 8) with AB-400 antenna unit is designed for detecting various objects (metal and nonmetal articles underground, underwater and in cavities) and for studying the homogeneity of soils. The penetrating radar operates based on the property of radio waves to reflect from the interface of media with different dielectric permeability. The radar with central frequency of 400 MHz, sounding pulse duration of 1 to 5 ns and scanning resolution of 5 to 10 cm has a maximum sounding depth of 4.0 to 5.0 m for dry soils.

Picture 8: *GPR «OKO-M1» with antenna unit AB-400*

The scanning was performed all round the supports and in the coastal area near the supports to determine the homogeneity of soils, the ground water level, and the presence of cavities. The survey diagram is shown in Figure 3. The scanning profiles (radargrams) of the survey area are shown in Figure 4. The radargrams have been obtained by computer-aided processing with the GeoScan-32 software.

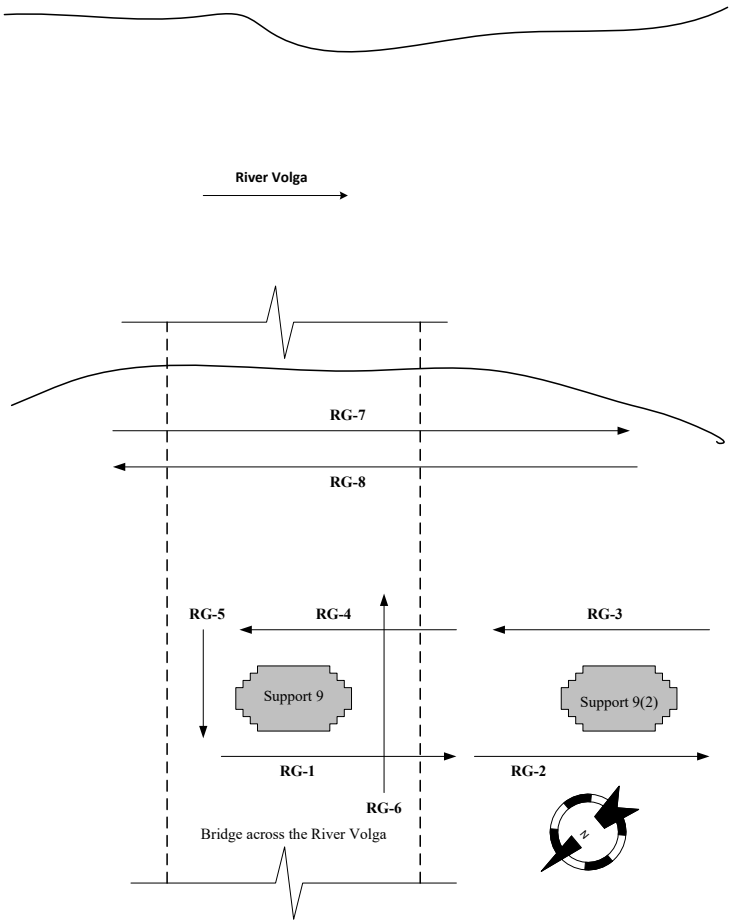
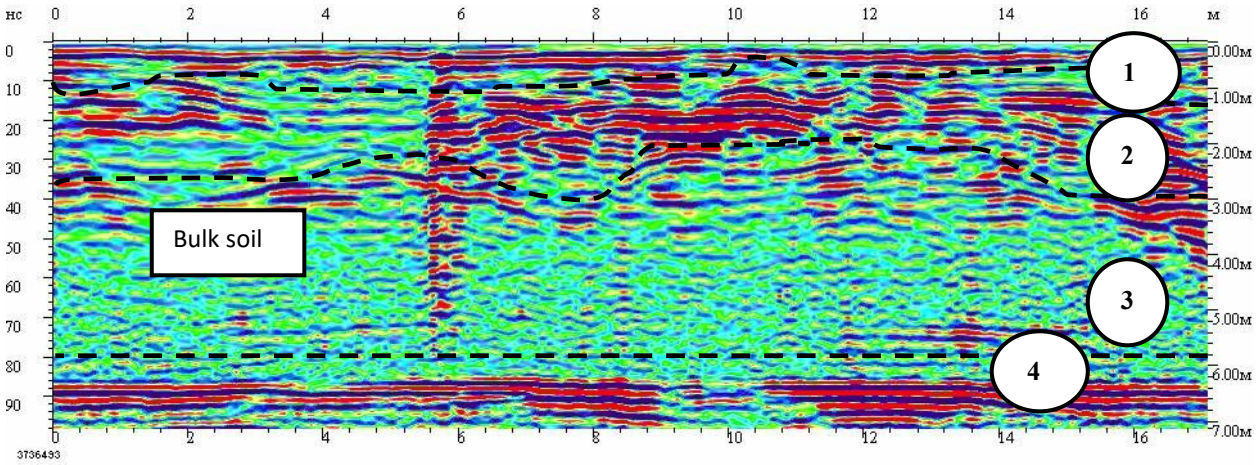


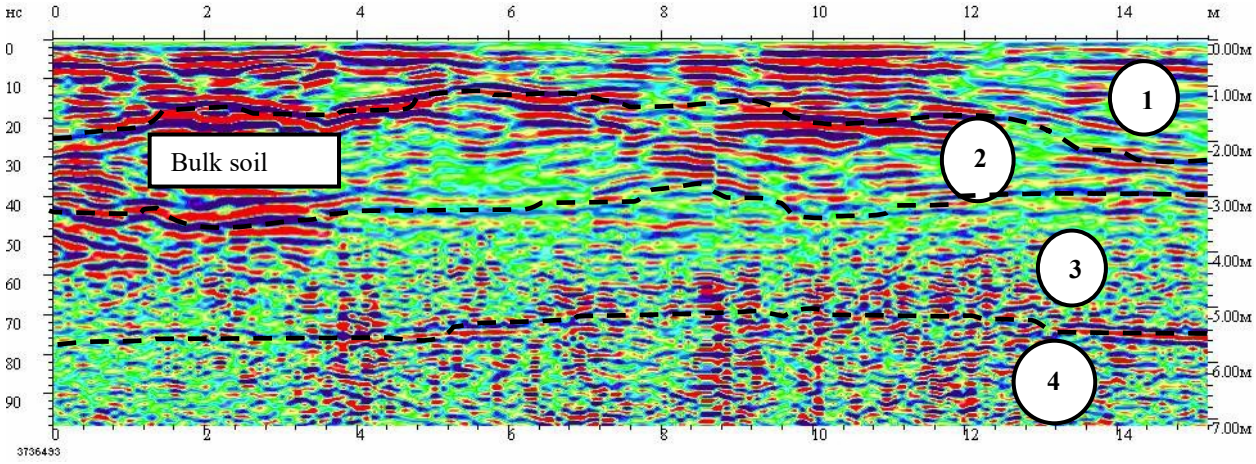
Figure 3: *Ground penetrating radar survey near supports No. 9*

RG-1 Surface scanning profile



There is a uniform occurrence of soils without sharp differences in depth. The bulk soil consists of three layers. The thickness of the bulk soil is 6.2-6.3 m, then the bedrock lies.

RG-2 Surface scanning profile



There is a uniform occurrence of soils without sharp differences in depth. The bulk soil consists of three layers. The thickness of the bulk soil is 5.2-5.8 m, then the bedrock lies.

Figure 4: *Radargrams of soil on profile 1 u 2*

5) Dynamic testing of structures

The identification of the bridge dynamic parameters and the bridge structure hidden defects required to use loading devices; three-component seismic detectors; connecting cables; multi-channel analog-to-digital converters; computers with a software package for seismic vibration signal analysis [2].

The dynamic tests are conducted to determine dynamic and stiffness properties, load-bearing capacity of structural members of buildings and structures, and to detect any hidden defect (Figures 5, 6).

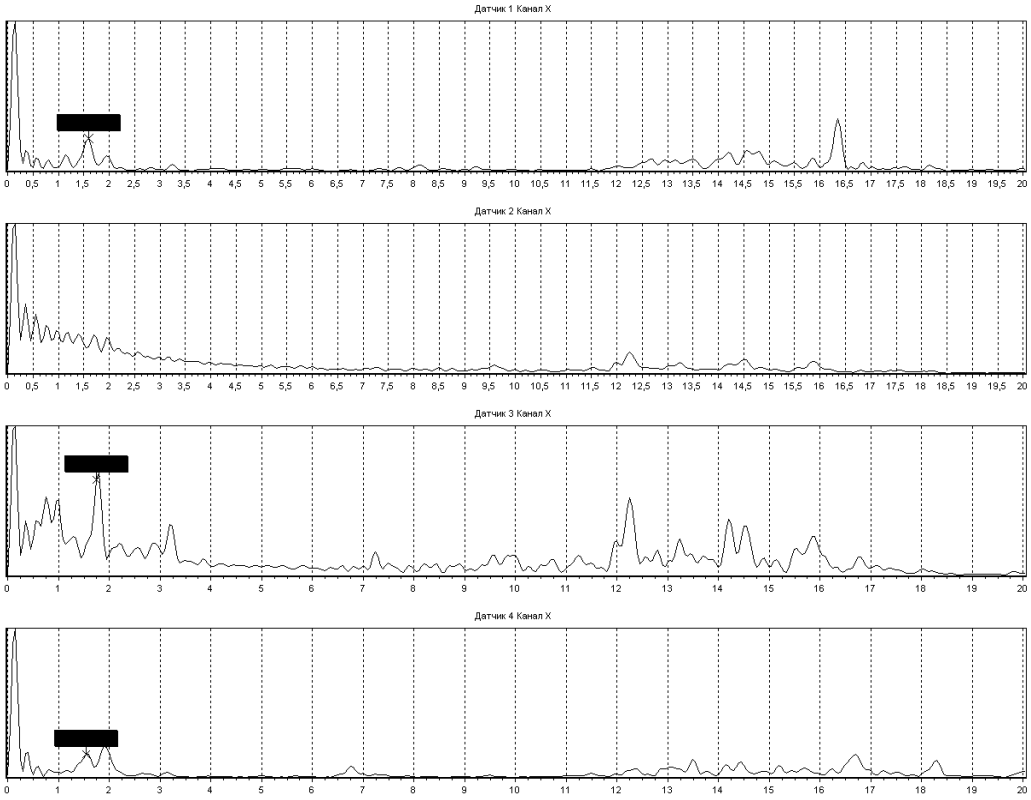


Figure 5: *The natural vibrations of the bridge along the X axis*

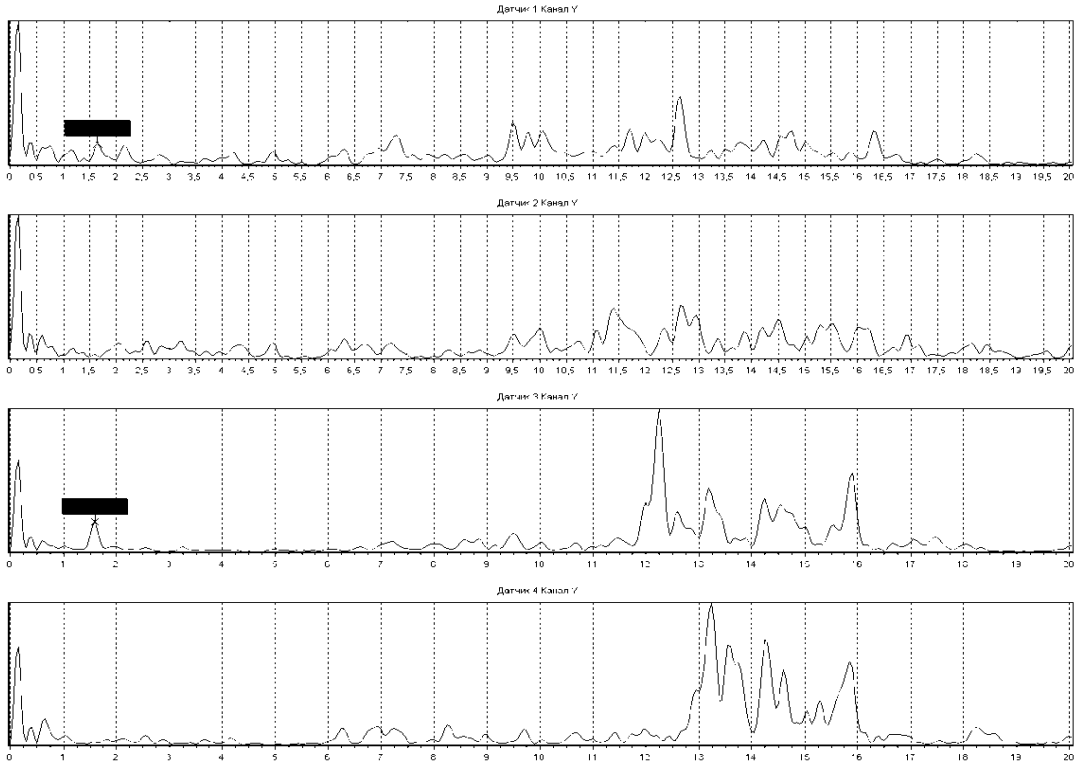


Figure 6: *Natural vibrations of building block 1 along the Y axis*

Measurements during wind gusts have been conducted (Figures 7).

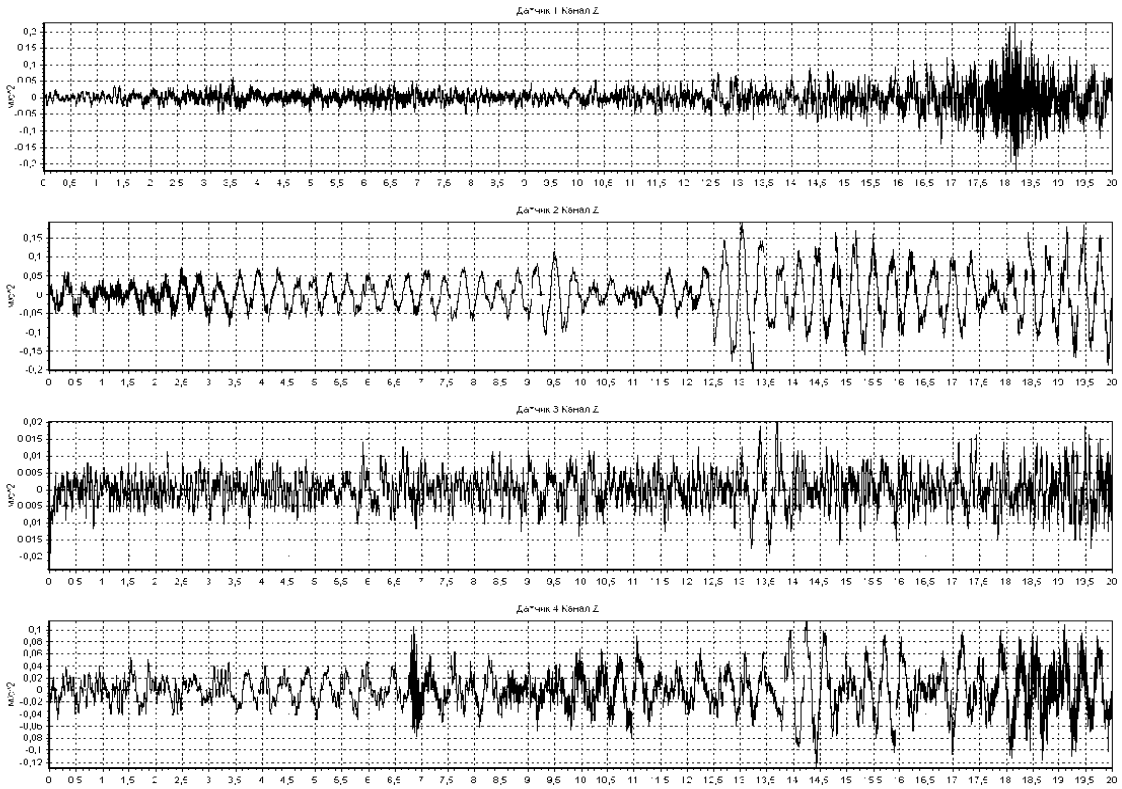


Figure 7: *Accelerations along the X-axis in the middle part of the bridge in small wind gusts*

Instruments have been used for the dynamic testing of the ground-to-structure system with the dynamic parameters of the structures obtained. The natural period of structural system oscillations as the basic dynamic parameter is known to relate to *EJ* stiffness thereof. Therefore, the dynamic test results to increase the natural period of oscillations *T1* of a structure are going to yield the value of reduction in the structure integral stiffness. Mathematically, the dependency of the natural period on the stiffness can be expressed as:

$$T_1 = \kappa\sqrt{\frac{m}{EJ}}$$

where
κ is a factor accounting for the type and dimensions of the structural layout,
m is mass of the structure,
E is modulus of elasticity,
J is moment of inertia.
Generally, the natural period of oscillations *T1* features the structural system's stiffness. Afterwards, the integral reduction in the inertia moment will show the potential defects in the sections of the structural members of the structure. A reduction in the modulus of elasticity shows that an integral reduction in the strength of the structural members occurs.
From the design data: *T1* norm. = 2.4 sec.
The survey and acceptance test results of the structure have shown that the natural periods of oscillations of the structure for spans 8-9 and 7-8, respectively, are equal to:
T = 0.37 sec;
T1y = 1.67 sec;
T2 = 0.4 sec.
For city bridges, the natural period of oscillations of the first 2 modes should not fall within the range of 0.45 to 0.6 sec.
The test results have shown the natural periods of oscillations of the structure to be, respectively, equal to:
T1x = 0.3-0.5-0.625 sec;
T1y = 0.3-0.5-0.625 sec;

I.e., the dynamic test results show the oscillation periods of the bridge to fall within the range of 0.45 to 0.6 sec with reference to car traffic movement and light wind gusts, and this proves that the bridge is subject to dynamic impacts.
In addition, the wind gusts were found to lead to a "play" phenomenon on the bridge, with 3-4 sec period. With the same period, but greater amplitudes, critical "play" oscillations were occurring, which led to the stopping of the movement [4].

III. Results

No visually identifiable defects have been found in the load-bearing structures of the bridgework. The ultrasonic testing yielded the following results:
- the strength (of mw between supports 9 and 10) is varying between 39.37 and 42.04 MPa (up to 6 % of the maximum), the average values being between 34.53 and 39.56 MPa. The ground scanning suggests the following conclusions:
- the backfill soil thickness in this geological area is 6.2 to 6.3 m, as followed by deeply formed alluvial soils;
- no substantial changes have been found in the soil mass.

Generally, the soils have been found to lay evenly, with no abrupt depth changes. In general, the geologic conditions of the area are considered favorable upon the ground penetrating radar scanning. The visual, strength, and geodetic surveys yielded no changes in the technical condition of the bridge. The wind gusts turned out to lead to a "play" phenomenon on the bridge with 3-4 sec period [2, 3]. With the same period, but greater amplitudes, critical "play" oscillations were occurring, which led to the stopping of the movement. During storm winds the bridge will be periodically subject to the "play" or critical "play" phenomena. This paper provides the measured data of the bridge, which have been obtained with the use of the methods applied. The application of such methods improves the specialist knowledge.

IV. Conclusions

The analysis shows that the monitoring of bridge structures from the point of view of the users of bridge structures aims at the following important tasks: ensuring the preservation of bridge structures; increasing durability bridges structures by timely detecting damage and repairing it in a timely manner; maintaining the load capacity of bridge structures by managing their behavior during operation; improving the efficiency of expenditure on repair increase efficiency of expenses for repair works by means of correct determination of time and types of necessary increase cost efficiency of repair works by correct timing and type of necessary repairs [2, 3, 4, 5].

References

[1] Kappos, A.J. (2001). Dynamic Loadind and Design of Structures. London and New York.

[2] Rotaru, A.N. and Savinov, A.M. (2021). Civil Security Technology 18(3) (69) 53-55.

[3] Savinov, A.M., Rotaru, A.N., Nigmetov, G.M. (2020). Determination of vulnerabilities in of multi-storey buildings by the method of dynamic-geophysical tests, Proceedings of Section No. 12 XXX International Scientific and Practical Conference PREVENTION. RESCUE. HELP" 113-118, Himki, Russian Federation.

[4] Rotaru, A.N., Nigmetov, G.M., Maklakov, A.S., Gaifullin, Z.G. (2021). Civil Security Technology 18(1) (67), 46 –53.

[5] Sardar Kashif Ur Rehman, Zainah Ibrahim, Shazim Ali Memon, Mohammed Jameel, (2016). Construction and Building Materials Volume 107, 58-86.

[6] Todorov, E.I. (2022). Encyclopedia of Materials: Metals and Alloys, Volume 3, 168-192.