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SOLVING THE PROBLEM OF LARGE CONSTRUCTION SAFE OPERATION

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Abstract:
Bridge construction has a significant amount of data on the periods of trouble-free operation of bridges of various designs and purposes. These data serve as a reliable basis for developing schedules of planned preventive inspections and repairs of bridge structures. However, the statistical nature of this information does not exclude the occurrence of seemingly unpredictable events (destruction of the road surface, loss of stability and destruction of the load-bearing elements of the bridge structure). These events usually occur suddenly, although this is only an external manifestation of hidden processes that occur naturally in the structure up to a certain point in time starting from the moment it is put into operation. To outline these processes, the presented article proposes to describe the bridge structure as a dynamic system developing in an "acute mode". The mathematical model describing such a dynamic system contains a parameter equal to the time coordinate when a radical change in the law of development of the controlled dynamic system occurs. The testing of the bridge life using forecasting methodology was carried out on the example of a cable-stayed bridge and confirmed its effectiveness.

Key words: period of trouble-free operation of a bridge, schedule of planned preventive inspections and repairs, statistical nature of information, unpredictable events, dynamic system, mode with aggravation, cable-stayed bridge

INTRODUCTION

The significant volume of statistics collected worldwide on the results of operation of bridge structures of various designs and purposes, including cable-stayed ones, allows us to develop a reliable plan of scheduled preventive maintenance (SPM) for each bridge put into operation. The use of such schedules ensures the required level of safe operation of bridges. However, the statistical nature of this information allows for the occurrence of sudden events, which can cause unexpected stops of the bridge for unscheduled inspection and repair. Suddenness is an external manifestation of deep, naturally occurring processes in the bridge structure, starting from the moment the bridge is put into operation. To avoid such events, the SPM schedules must be supplemented with forecasts of the specified unscheduled stops for inspections and repair work. The solution to this problem is especially relevant for critically important elements of the state's transport infrastructure. The solution to this problem is the implementation of a continuous monitoring system for the bridge condition, which is a set of functionally integrated monitoring instruments installed on the bridge and related objects providing measurement of physical quantities, transmission, processing, analysis and provision of information to service personnel in continuous mode. Thanks to this, all necessary information about the condition of the bridge structure is continuously and automatically collected, processed and sent to the control structure at the right moment when there is still an opportunity to take preventive measures. In this case, if traditional control measures (periodic inspections and surveys of the facility) are insufficient to manage the existing risks, it is advisable to equip the facility with an instrumental measuring system that will allow continuous monitoring of the condition of the bridge structure. One of the key indicators of the technical condition of the bridge deck is its vertical deflection, which changes over time and can serve as an indicator of increasing defects and the approach of a potential accident. Forecasting the service life of bridges based on the analysis of the dynamics of vertical deflection of the road surface allows us to set in advance the time of an unscheduled stop for inspection and possible repair of cable-stayed bridges. This approach is based on mathematical modelling of the patterns of structural deformation and allows determining the time for timely shutdown of the bridge for preventive repairs long before the critical point of its destruction. The method of forecasting the technical condition of engineering structures, which is considered in the article, is a promising direction that allows specifying the terms of operation and minimizing the risks of sudden accidents. The work contemplates the mathematical justification of the method, examples of its application and an analysis of the effectiveness of the proposed approach.

LITERATURE REVIEW

As the logistical load on bridge structures, especially cable-stayed ones, increases, so does the need to predict their actual service life. This requires modern instrumental control of bridge structures and effective methods for analysing the results.

Thus, the goal set in [1] was to determine the service life of a reinforced concrete bridge structure based on the endurance criterion of the tension zone reinforcement. To this end, the factors influencing the durability of reinforced concrete structures operating under repeated loads were considered and analysed. A model was proposed to determine the durability of a reinforced concrete structure based on the endurance of tensile reinforcement. This takes into account the number of loading cycles of the structure per unit of time, the plastic deformation of the reinforcement and the parameters of the concrete's specific creep deformation. This enabled the possibility of predicting the service life of a reinforced concrete bridge structure before it was required to stop for repairs to be carried out. Authors in [2] present a new approach to determining the maximum wear of road bridges by incorporating a numerical reliability parameter into the wear calculation model. In the operational system, this provides a quantitative criterion for predicting the technical condition of bridge elements. Article [3] presents proposals for assessing the reliability of operational bridge structures and calculating the probability of their destruction. It presents the most common causes of defects in bridge structures. Typical measures for restoring the operational qualities of bridge structures are also proposed. Authors in article [4] describe new bridge structures, including a series of cable-stayed structures.

In article [5], a model for predicting the reliability of the operating superstructures of highway bridges is proposed. Based on the actual reliability of reinforced concrete bending elements at the time of technical inspection, it allows us to determine the initial reliability and predict changes in reliability over time. It also enables us to determine the residual life when the required reliability is achieved. Several works [6, 7] examine the analysis of the technical condition of highway bridges in Ukraine in detail, showing that the actual service life of reinforced concrete bridge structures is 25-30 years, which does not correspond to the potential capabilities of reinforced concrete as a material. The poor technical condition of bridges poses a serious threat to the efficient operation of the road network and results in significant socio-economic losses for the country. Operating bridges as they are today leading to a reduction in their service life, a decrease in reliability and an increase in risk [8]. Several articles [9-11] indicate that regulatory documents lay the foundations for managing the reliability of road bridge elements throughout their entire life cycle. However, these documents require further development to determine design reliability and the dependence of actual reliability on initial reliability. They also need to consider how the reliability of bridge elements changes over time in relation to wear processes. Nevertheless, the limit state methodology, according to which reinforced concrete bridge elements are designed, does not contain a time variable and only ensures the structure's instantaneous reliability at the time of construction. The subsequent wear process under the influence of various external factors is not clearly considered by the necessary dependencies.

Authors of article [12] examine a model for evaluating the condition of bridge components based on regulatory documentation. This model is based on the theory of random Markov processes. The technical condition indicator is the reliability of the bridge element during operation. In [13, 14], a model for the degradation of reinforced concrete bridge structures over time is proposed which describes the reduction in bearing capacity of the superstructure using a single parameter. The following materials note that errors in the design, construction and operation of bridges can significantly reduce their actual service life [15, 16], which is typically 30-50 years. To compensate for this negative phenomenon, in addition to the adopted scheduled maintenance schedules, it is necessary to develop backup measures using forecasts of unscheduled shutdowns of the facility for inspection and preventive repairs before an accident occurs [17, 18, 19].

This article considers one possible method of forecasting the service life of a cable-stayed bridge before an unscheduled shutdown for repairs [20, 21]. This method differs fundamentally from those used in bridge construction and is based on the concept of a bridge structure as a dynamic system that develops in an 'aggravation mode' [22]. The article presents an example of forecasting an unscheduled bridge shutdown for inspection. This is a modern approach to ensuring the safety of a strategically important technical structure.

METHODS, RESULTS AND DISCUSSION

In dynamic systems developing in blow-up mode, a periodic process is superimposed on the main trend of the controlled parameter. This process is described by a model, one of whose coefficients coincides in value and dimension with the moment of system destruction or a radical change in the law of its development [22].

Such modes are described by the following equation

$$\frac{dx}{dt} = x^{1+1/\alpha}. \tag{1}$$

The equation solution increases without limit as we approach the peaking moment t_f:

$$x(t) \sim \left(t_f - t\right)^{-\alpha}. \tag{2}$$

To obtain a solution acceptable for practice (2), we pass from the real indicator a to the complex one $\alpha + \beta i$, which allows us to obtain an equation of the following form:

$$\begin{aligned} x(t) &= \mathrm{Re} \textstyle\sum_k \, a_k \left(t_f - t\right)^{-\alpha + k\beta i} = \\ &= \left(t_f - t\right)^{-\alpha} \cdot F\left(\ln\left(t_f - t\right)\right). \end{aligned} \tag{3}$$

The function $F(\cdot)$ is described by several multiple harmonics, characterizing in the general case the significant nonlinearity of systems developing in the blow-up mode. However, in practice [15], the function $F(\cdot)$ is limited to one first harmonic:

$$x(t) = \left(t_f - t\right)^{-\alpha} \cdot \left(a_0 + a_1 \cos\left(\beta \cdot \ln \frac{t_f - t}{\tau}\right)\right). \tag{4}$$

This expression is a smooth trend, on which log-periodic fluctuations are superimposed, which serve as precursor of approaching the blow-up moment t_f. Taking $t \to t_f$ the oscillation frequency tends to infinity, which meets the dynamic law requirements followed by the blow-up mode. The continuous increase in the log-periodic oscillations frequency allows them to react sensitively to the course of catastrophically developing processes long before the blow-up moment.

If the moment of exhaustion of the bridge resource T is considered as the moment of destruction t_f, then the process of operation of the bridge can be attributed to blow up modes. At the same time, to improve the quality of predicting bridge life, it is necessary to isolate the sensitive log-periodic part of the recorded signal. In practice, this means that the total signal periodic component must be separated from the smooth trend and its behaviour should be analysed separately throughout the entire process of operation of the bridge.

The periodic component model should be subjected to direct analysis, which fully describes the complex polyharmonic in structure of the recorded signal.

The controlled parameter $A_{CON}(t)$ is considered as the sum of the smooth (trend) B_{TR} and the periodic component A_{PER}.

$$A_{CON}(t) = B_{TR} + A_{PER}. \tag{5}$$

According to (5), at $T = t_f$, B_{TR} is determined from the following expression

$$B_{TR} = a_0 \cdot (T - t)^{-\alpha}. \tag{6}$$

The periodic component A_{PER} is extracted from the information (total) signal A_{SUM} by decomposing it into empirical modes [23].

$$A_{PER} = -0.25 A_{SUMi-1} + 0.5 A_{SUMi} - 0.25 A_{SUMi+1}. \tag{7}$$

The periodic component A_{PER}, according to (5), is determined from the following expression

$$A_{PER} = a_1 \cdot \cos\left(\beta \cdot \ln \frac{T - t}{\tau}\right) \tag{8}$$

For the convenience of further research, expression (2) should be reduced to the classical form of the log-periodic function (9), considering it as a B_{MOD} model of the periodic component A_{PER}.

$$B_{MOD} = A_0 \cos\left(\omega \cdot \ln(T - t) - \varphi\right),$$

where: (9)

$$A_0 = a_1 \cdot (T - t)^{-\alpha}; \omega = \beta; \varphi = \beta \cdot \ln(\tau).$$

Expression (9) contains fore unknown parameters: T, ω, φ, A_0. The first three parameters are determined by solving the system of two nonlinear equations (10).

$$\begin{cases} \ln(T - t_n) - \ln(T - t_{n+1}) = \frac{2\pi}{\omega} \\ \ln(T - t_{n+1}) - \ln(T - t_{n+2}) = \frac{2\pi}{\omega} \end{cases} \tag{10}$$

Equations (10) are based on the knowledge of the time t_n, which account for the extremes A_{EXT} of the periodic component A_{PER}.

To search for these extremes, the following algorithm is used

- at least three local extremes stand out in the periodic component A_{PER}. They are separated from each other in phase by an angle 2π, and there are consecutive and identical in sign (maximum or minimum);
- the time t is marked when extremes occur (t_n, t_{n+1}, t_{n+2});
- the parameter ρ is calculated that characterizes the relationship between the extreme's occurrence time.

$$\rho = \frac{t_{n+1} - t_n}{t_{n+2} - t_{n+1}}, \rho > 1 \tag{11}$$

Parameter ρ must exceed one. This indicates a decrease in the period of its oscillations, characteristic of the log-periodic function, over time.

A decrease in the period leads to an increase in the oscillation frequency of the log-periodic function in the limit to infinity. This function feature was the basis for choosing it as a model B_{MOD} (9) for describing systems operating in the blow-up mode [22]. The set of extremes forms an array composed of discrete values of A_{EXT} extremes of the periodic component A_{PER}.

The solution of system (10) gives the following expressions for the first three unknowns of equation (9) [24]:

$$\begin{gathered} T = \frac{t_{n+1}^2 - t_{n+2} t_n}{2t_{n+1} - t_{n+2} - t_n}, \\ \omega = 2\pi / \ln(\rho), \\ \varphi = \pi - \omega \cdot \ln(T - t_{n+2}). \end{gathered} \tag{12}$$

To check the correctness of the obtained unknowns' values (12) and, if necessary, to refine them, the difference between the components of the array of extreme values A_{EXT} and their model B_{MOD} (9) is minimized. In this case, the parameter A_0 is also determined.

$$\textstyle\sum_i^m \left(A_{EXTi} - B_{MODi}\right)^2 \Rightarrow \min \tag{13}$$

In practice, knowledge of the value of the residual resource of T_{rul} is of interest.

$$T_{RUL} = T - t. \tag{14}$$

As calculated, the minimization of function (13) is carried out step by step in a time window expanding from left to right. The expansion is carried out until the moment of exhaustion of the number of members of the experimentally determined time series. The number of predicted values of the parameter T_{RUL} forms a predicted time series, the number of members of which is equal to the number of steps along the time axis *t*, starting from the fourth step.

The subject of the survey was a cable-stayed bridge. The cable-stayed part of the bridge is 271 m.

To demonstrate the fundamental feature of the considered method of forecasting the service life of a bridge, a significant amount of initial data was reduced. As such, measurements in three sections of the cable-stayed part of the bridge, performed along its centreline at the beginning, middle and end (Fig. 1) of the cable-stayed part of the span, were considered.

The absolute values of the vertical deformation of the road surface were measured using a modern laser displacement meter [25, 26].

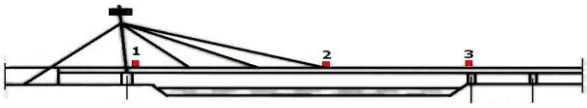

Fig. 1 Layout of information points for laser measurement of vertical displacement on the cable-stayed part of the bridge

The results of predicting the service life of a cable-stayed bridge before it is shut down for repairs are shown in Fig. 2-3 and in the protocol (Fig. 4). Fig. 2 shows typical waveforms characterizing vertical displacements of the deck, recorded at the bridge control points by a modern high-precision digital system [27, 28] and a laser displacement meter [29, 30, 31, 32, 33, 34].

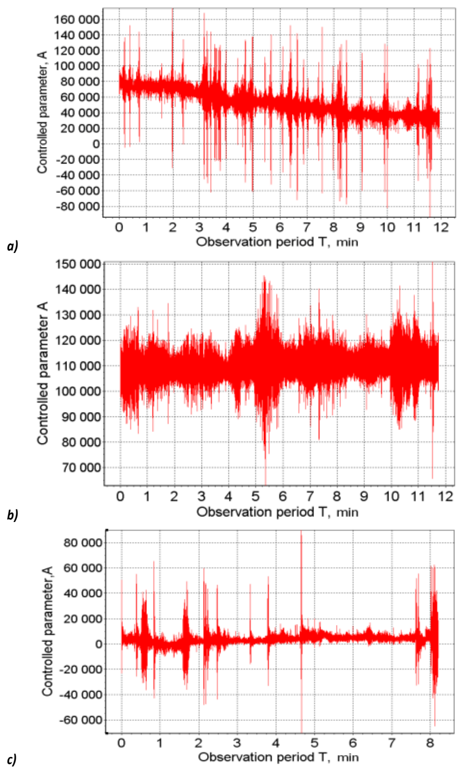

Fig. 2 Typical signal shape recorded during regular monitoring of the bridge condition at points: a) No. 1, b) No. 2, c) No. 3

Fig. 3 shows the forecast of the service life of the bridge *Tpr* before it is stopped for inspection and a decision is made on the advisability of carrying out its repair. A duration of 100 years was taken as a lead time.

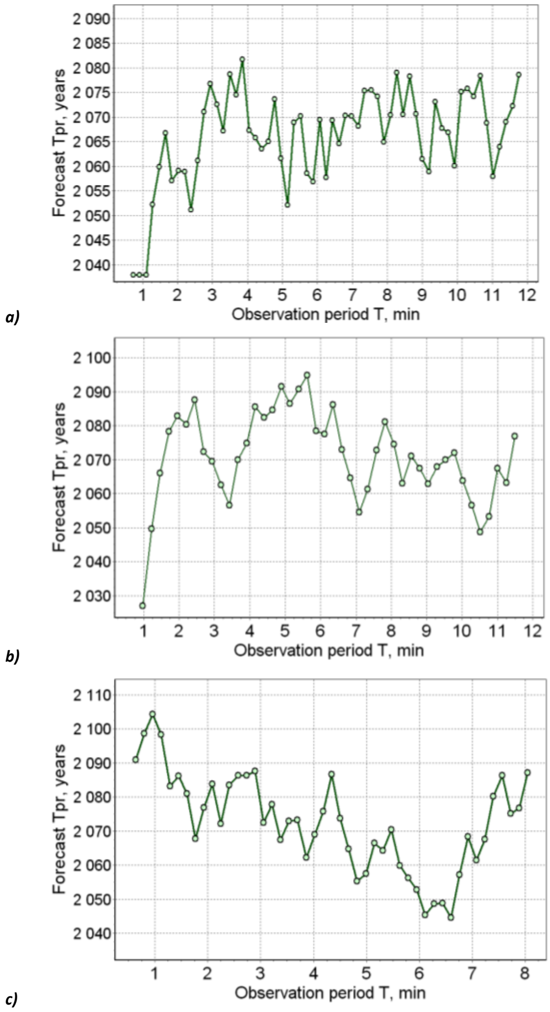

Fig. 3 Forecast the bridge remaining useful life TRUL, based on signal recording at points:
a) No. 1, b) No. 2, c) No. 3

The ***"Forecast protocol…"*** of the date of stopping the bridge for an unscheduled inspection to decide on preventive repairs is shown in Fig. 4.

a)	*The forecast of the most probable date of stoppage for repairs is:* ***July 23, 2078*** *and changes with a confidence probability* ***P = 0.95*** *within the following limits:* *from May* ***8, 2078,*** *to October* ***8, 2078***
b)	*The forecast of the most probable date of stoppage for repairs is:* ***November 9, 2076*** *and changes with a confidence probability* ***P = 0.95*** *within the following limits:* *from* ***April 2, 2076,*** *to June* ***16, 2077***
c)	*The forecast of the most probable date of stoppage for repairs is:* ***February 1, 2087*** *and changes with a confidence probability of* ***P = 0.95*** *within the following limits:* *from July* ***18, 2086,*** *to* ***August 12, 2087***

Fig. 4 Protocol for predicting the service life of a bridge before unscheduled repairs, based on signal recording at points: a) No. 1, b) No. 2, c) No. 3

As follows from the *"Forecast Protocol …",* the beginning of the cable-stayed part of the bridge (point No. 1) will require inspection in July 2076, and the end (point No. 3) – only in February 2087. The middle of the cable-stayed part (point No. 2), like its beginning, will require inspection in November 2076.

CONCLUSIONS

1. Bridge construction has a significant amount of data on the periods of trouble-free operation of bridges of various designs and purposes, which serve as a reliable basis for developing schedules for scheduled preventive inspections and repairs of bridge structures.
2. The statistical nature of information on the service life of bridges allows for sudden destruction of the road surface, loss of stability and destruction of the load-bearing elements of the bridge structure.
3. As a rule, these events occur suddenly, although this is only an external manifestation up to a certain point in time of hidden processes that naturally occur in the structure starting from the moment it is put into operation [35].
4. To predict the behaviour of a bridge structure, throughout its entire service life, the bridge should be considered as a dynamic system developing "in an aggravation mode," which allows for an original approach to predicting the resource, including heavily loaded bridge systems such as cable-stayed ones.
5. The mathematical model of the dynamic system of a bridge developing in an "acute mode" contains a parameter equal to the time coordinate corresponding to a radical change in the behaviour of the bridge structure up to and including destruction.
6. The testing of the bridge service life forecasting method discussed in the article was carried out on the example of a cable-stayed bridge and confirmed its effectiveness making it possible to forecast the time of an unscheduled bridge stop for inspection and decision-making on the need for and scope of its repair.

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REFERENCES

[1] O.I. Dubinchik, V.R. Kildeev. "Prognozirovanie resursa zhelezobetonnykh konstruktsii po vynoslivosti armatury [Prediction of the service life of reinforced concrete structures based on reinforcement fatigue]". *Mosty ta tuneli: teoriya, doslidzhennya, praktyka*, no. 7, pp. 13-18, 2015. (in Russian)

[2] A.I. Lantukhov-Lyashchenko, K.V. Medvedev. "K voprosu opredeleniya granichnogo iznosa stalezhelezobetonnoho proletnoho stroeniya avto-dorozhnogo mosta [On the issue of determining the ultimate wear of steel-reinforced concrete spans of highway bridges]". *Vestnik KHNADU*, no. 58, pp. 90-95, 2012. (in Russian).

[3] S.S. Rekunov. "Ob otsenke nadyozhnosti i vosstanovlenii ekspluatatsionnykh kachestv mostovykh sooruzheniy [On the assessment of reliability and restoration of operational qualities of bridge structures]". *Internet-journal "Transportnye sooruzheniya"*, vol. 3, no. 2, pp. 1-8, 2016. (in Russian)

[4] A.V. Perelmuter, M.M. Korneev. "Ukrainskaya shkola proektirovaniya stalnykh mostov [Ukrainian school of steel bridge design]". *Zbirnyk naukovykh prats Ukrainskoho instytutu stalevykh konstruktsiy imeni V.M. Shymanovskoho*, vol. 25-26, pp. 106-143, 2020. (in Ukrainian)

[5] I.V. Kandaeva, D.I. Borodai. "Issledovanie nadyozhnosti zhelezobetonnykh proletnykh stroeniy avto-dorozhnogo puteprovoda [Study of the reliability of reinforced concrete spans of a highway overpass]". *Modern Industrial and Civil Construction*, vol. 13, no. 2, pp. 47-56, 2017. (in Russian)

[6] A.I. Lantuh-Lyashchenko, P.M. Kovalov. "On the question about creation of national framework of bridge operations". In: *Diagnostic operation, longevity and regeneration of bridges and building constructions by applying high technology and materials*, issue 1, edited by V.V. Panasiuk, Lviv: Kameniar, pp. 70-76, 1998. (in Ukrainian)

[7] P.M. Koval. "Development of the management system of highway bridges of Ukraine". In: *Roads and Bridges*, Kyiv: DerzhdorNDI, issue 11, pp. 133-145, 2009. (in Ukrainian)

[8] O.I. Nigamatova, I.G. Ovchinnikov. "Systems of state management bridges". *Naukovodenie*, vol. 7, no. 3, 2015. Mode of access: http://naukovedenie.ru/PDF/09TVN315.pdf.

[9] DBN V.2.3-22:2009. "Bridges and tubes. Dominant requirements of design". Kyiv: *Ministry of Regional Development of Ukraine*, 52 p., 2009. (in Ukrainian)

[10] DBN V.2.3-14:2006. "Bridges and tubes. Design rules". Kyiv: *Minbud of Ukraine*, 359 p., 2006. (in Ukrainian)

[11] DSTU-N B V.2.3-23:2009. "Guidelines for assessing and forecasting the technical condition of highway bridges". Kyiv: *Ministry of Regional Development of Ukraine*, 49 p., 2009. (in Ukrainian)

[12] A.I. Lantuh-Lyashchenko. "Otsinka nadijnosti sporudy za modelem Markovs'koho vypadkovoho protsesu z dyzkretnymy stanamy [Reliability assessment of a structure based on the Markov random process model with discrete states]". *Avtomobilni dorohy i dorozhnye budivnytstvo*, issue 57, pp. 183-188, 1999. (in Ukrainian)

[13] L.I. Iosilevskiy. "Prakticheskie metody upravleniya nadyozhnost'yu zhelezobetonnykh mostov [Practical methods for managing the reliability of reinforced concrete bridges]". Moscow: *Nauchn.-izd. tsentr "Inzhener"*, 324 p., 2005. (in Russian)

[14] V.V. Panasyuk, Y.Y. Luchko (Eds.). "Mosty: konstruktsii ta nadijnist' [Bridges: Structures and reliability]". Lviv: Kameniar, 989 p., 2005. (in Ukrainian)

[15] L. Sukhodub, A. Panda, K. Dyadyura, I. Pandova and T. Krenicky. "The design criteria for biodegradable magnesium alloy implants". *MM Science Journal*, pp. 2673-2679, 2018.

[16] A. Panda, V.M. Anisimov, V.V. Anisimov, K. Dyadyura and I. Pandova. „Increasing of wear resistance of linear block-polyurethanes by thermal processing methods." *MM Science Journal*, vol. 21, pp. 4731-4735, 2021.

[17] I. Pandová, M. Rimár, A. Panda, J. Valíček, M. Kušnerová and M. Harničárová. "A study of using natural sorbent to reduce iron cations from aqueous solutions." *International Journal of Environmental Research and Public Health*, vol. 17, 2020.

[18] M. Harnicarova, J. Valicek, M. Kušnerová, J. Kmec, Z. Palková, I. Kopal, J. Krmela and A. Panda. "Study of the influence of the structural grain size on the mechanical properties of technical materials". *Materialwissenschaft und Werkstofftechnik*, vol. 50, no. 5, pp. 635-645, 2019.

[19] L. Sukhodub, A. Panda, L. Sukhodub, M. Kumeda and P. Baron. "Hydroxyapatite and zinc oxide based two-layer coating, deposited on Ti6Al4V substrate." *MM Science Journal*, pp. 3494-3499, 2019.

[20] A. Panda, M. Prislupčák and I. Pandová. "Progressive technology diagnostics and factors affecting machinability." *Applied Mechanics and Materials*, vol. 616, pp. 183-190, 2014.

[21] A. Panda, J. Duplák. "Comparison of Theory and Practice in Analytical Expression of Cutting Tools Durability for Potential Use at Manufacturing of Bearings". Operation and Diagnostics of Machines and Production Systems Operational States II, pp. 300-307, 2014.

[22] A.V. Podlazov. "Regimes with aggravation with complex indicators. Log-periodic oscillations in the model of fiber bundle rupture". *Preprints of the IPM im. M.V. Keldysh*, no. 35, 22 p., 2009.

[23] N.E. Myasnikova. "Decomposition into empirical modes based on extremal filtration". *Digital Signal Processing*, no. 4, pp. 13-17, 2014.

[24] O.V. Urentsov. "Checking the possibility of predicting crises in the financial market using the D method". *Proceedings of the ISA RAS*, vol. 40, pp. 174-191, 2008.

[25] Opis tsyfrovoi systemy otrymannia lazernykh danykh z mosta [Description of the digital system for obtaining laser data from the bridge]. Available at: http://seismo.kiev.ua/pubs/SeismoStUK16UK15OnLine2008.pdf (in Ukrainian)

[26] "Opis sertyfikatsii vymiriuvalnykh lazernykh kompleksiv dlia mostiv" [Description of the certification of measuring laser complexes for bridges]. Available at: http://seismo.kiev.ua/pubs/230200ArticleText53105511020210524.pdf (in Ukrainian)

[27] S.V. Shcherbina, Yu.V. Lesovoy. "Programmnoe obespechenie telemetricheskoi sistemy sbora i obrabotki mikroseismicheskikh dannykh v rezhime on-line" [Software for a telemetry system for collecting and processing microseismic data in real-time]. *Geodinamika,* vol. 1, no. 7, pp. 110-115, 2008. (in Ukrainian)

[28] S.V. Shcherbina, A.I. Feshchenko, Yu.V. Lisovyi, A.P. Ivashchenko, O.V. Adamenko, Yu.P. Soroka. "Kompleksnyi pidkhid do sertyfikatsii ta metrologichnoho otsiniuvannia suchasnykh tsyfrovykh seismometrychnykh reiestratoriv" [Comprehensive approach to certification and metrological evaluation of modern digital seismometric recorders]. *Geofizichecкiy zhurnal,* no. 2, vol. 43, pp. 201-217, 2021. (in Ukrainian).

[29] S. Shcherbina, A. Feshchenko, R. Nesterenko. "Vykorystannia lazernoi seismo-akustychnoi systemy v ramkakh DBN V.2.5-76:2014 dlia postiiinoho monitorynhu problemnykh mostiv" [Use of the laser seismic-acoustic system within the framework of DBN B.2.5-76:2014 for continuous monitoring of problematic bridges]. *II Mizhnarodna naukovo-praktychna konferentsiia im. P.M. Kovalia "Aktualni pytannia mostovoho hospodarstva ta shliakhy yoho pokrashchennia"*. 07-09 December 2022, Lviv, Ukraine. (in Ukrainian)

[30] O.V. Kendzera, R.B. Kotsur, P.G. Pihulevskyi, A.I. Feshchenko, S.V. Shcherbina. "Patent for a laser Seismological Laser Complex". *UA122603U*, no. 2/2018. (in Ukrainian)

[31] V. Nahornyi, A. Panda, J. Valíček, M. Harničárová, M. Kušnerová, I. Pandová, S. Legutko, Z. Palková and O. Lukáč. "Method of Using the Correlation between the Surface Roughness of Metallic Materials and the Sound Generated during the Controlled Machining Process". *Materials*, vol. 15, 823, 2022.

[32] A. Panda, V. Nahornyi, J. Valíček et al. "A novel method for online monitoring of surface quality and predicting tool wear conditions in machining of materials." *Int J Adv Manuf Technol,* vol. 123, pp. 3599-3612, 2022.

[33] Rozwadowski K., Konewecki A., Pasek R., Molski Sz.: Results of stress measurements on the guide rail supporting beams in a hoisting installation operated in the shaft Regis in relation to modelling data. *Min. Mach*. 2024, vol. 42 issue 2, pp. 90-107. DOI: https://doi.org/10.32056/KOMAG2024.2.1

[34] Szweda S., Wojtaszczyk M., Krenicky T.: Tests of selected elements of building components in the light of compulsory requirements. *Min. Mach*. 2022, vol. 40 issue 3, pp. 130-140. DOI: https://doi.org/10.32056/KOMAG2022.3.2

[35] A. Panda, K. Dyadyura, J. Valíček, M. Harničárová, M. Kušnerová, T. Ivakhniuk, L. Hrebenyk, O. Sapronov, V. Sotsenko, P. Vorobiov, V. Levytskyi and A. Buketov. "Ecotoxicity Study of New Composite Materials Based on Epoxy Matrix DER-331 Filled with Biocides Used for Industrial Applications." *Polymers,* vol 14, 3275, 2022.

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