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PROVIDING SAFETY FOR MINE SURFACE OBJECTS BY UPGRADING OF THE RELIABILITY LEVEL

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Abstract. The method for analyzing defect distribution as one of the methods for assessing the technical condition of structural elements of the mine surface constructions is developed. The defect distribution method determines future works on reliable operation and provides a high-leveled safety for the mine surface objects in terms of a stressed state of the structural elements at the design stage. The analytical model for determining physical wear of facility at survey was developed and its actual survivability was established. An object is considered as a system of hierarchically connected groups with the identical bearing elements for determining the standard levels of reliability. The main parameters considered in modeling are as follows: actual state and survivability of structural elements at their survey. The obtained model determines the state of the operated facility in the dependencies of the building bearing structures on its survivability. The threshold values of survivability are determined, at which the surface object of the mines passes into a qualitatively different state - from normal to satisfactory, from satisfactory to unsuitable, and from unsuitable to emergency. The proposed methodology for assessing the safety of operated surface structures can be used in practice to assess the degree of survivability, the technical condition and safe residual resource. The scientific novelty of the method proposed in the work is an adequate description of the technical state of the structural elements of the mine surfaces, which takes its place among the new modern experimental studies of materials and structures of the surface objects. The method for analyzing defect distribution enables to determine the safety and reliable operation for the surface objects of mines. The proposed measures improve the reliability of the operated facility, as well as preserve the lives for the enterprise's employees and tangible assets.

Keywords: mine surface objects, reliability, defect, stress state.

Introduction. Industrial surface objects at the mining enterprise are considered as a complex construction, representing an organized set of the identical constructions similar to foundation, walls, overlap, etc. The standard values of survivability are the average values at which the structural elements of the surfaces in mines pass into a different technical state. They are used to formulate the safety requirements for buildings and structures in assessing their technical condition.

Secondary mine facilities have traditionally been neglected compared to more important structures that directly affect the extraction of minerals. These factors necessitate to shorten the time for the construction, reconstruction and repair of mine facilities that are not associated with the production process: drop-towers, overpasses, surface buildings, etc. Sometimes shortening construction time is well worth, but often as a result of the reduction in terms, inadequate design solutions are covered up.

Another significant factor is a large number of objects which pose an immediate risk and are not subject to reconstruction or repair through known methods without stopping production. New methods of repair and reconstruction in terms of limited data of statistical information on the state of objects are required to be developed.

A large number of surface objects in the domestic and foreign mines are in urgent need of repair. A complete cessation of these facilities is required, in order to thoroughly study all the shortcomings and solve the problems of reconstruction or repair. It would result in the exclusion of one of the links in the technological process of the mine, and in turn would damage the enterprise. On the other hand, the threat of emergency collapse of unusable and emergency facilities requires an immediate solution.

Thus, a need emerged for conducting experiments further improving regulatory documents and developing new design methods.

The work of any technical system can be characterized by its efficiency, which means a set of properties determining the ability of the system to perform certain tasks created.

Reliability means a property of the object to keep the values of all parameters in time within the established limits, as well as an ability to perform the required functions in the defined modes and application conditions, maintenance, repairs, storage and transportation.

Thus, the basic concept of reliability is formulated as a property of an object to preserve in time its ability to perform the required functions; necessary functions must be performed at the values of the parameters within the established limits; ability to perform the required functions must be stored in preset modes and in the given conditions; the object must be able to perform the expected functions in different phases: in operation, maintenance and repair.

Reliability is an important indicator of the quality of the facility. It cannot be countered or confused with other indicators of quality. That is why the definition of the reliability concept includes the performance of the specified functions and the preservation of this property when using the object in the correct way.

Materials and methods. The results of numerous studies show that accidents and emergencies may be caused by different conditions:

- errors in design and reconstruction (inadequate consideration of solid conditions, application of various design schemes in one facility, change in the design scheme, incorrect selection of amplification, etc.);
- errors in construction and reconstruction (poor quality of construction and installation works, non-simultaneous erection of the facility parts, defective materials, unqualified implementation of the reconstruction project, etc.);
- errors in operation (karst formations, underground workings, uneven effects on structures, dynamic effects, etc.);
- unintended external influences as natural phenomena (squall wind, heavy precipitation, severe icing), and the result of human activity (explosions, collapses, strokes);
- the expiry of the service life of the facilities without performing scheduled repair and restoration works.

It is often impossible to evaluate the influence of the listed factors by the theoretical method. Hence, new modern experimental studies of materials and structures of facilities acquire special significance.

Formulation of the problem. The properties of building materials, bases, loads and impacts, operating conditions should be taken into account when assessing the technical condition of the surface objects. Minimizing the function of the technical state parameters makes possible to obtain the reliability function of the surface object as a whole and to provide an efficient system for analyzing the propagation of defects in conditions of the stressed state of the structural element.

Results. The first stage includes a general primary diagnosis shown in Fig. 1.

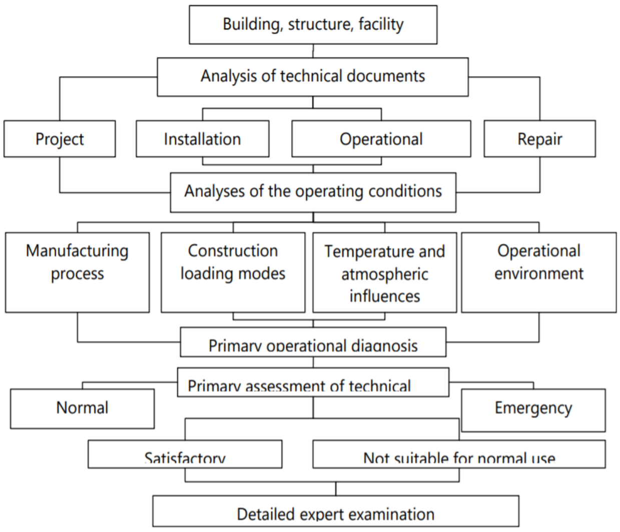

Figure 1. Basic stages of the general primary diagnostics of the object

The aim of the general primary diagnosis is to obtain complete data on the technical condition of the object at survey. Analysis of technical documentation, analysis of operating conditions, the initial determination of technical condition is carried out. The result of the primary diagnosis is an installation checklist indicating the technical condition of the facility and conclusions about a detailed expert examination.

Further, if necessary, a full expert examination is conducted. The aim is to obtain data on the actual technical condition of the facility, and identify the reasons and mechanisms for damage development. The full expert survey includes three main blocks: project compliance survey; experimental research; calculation by limiting states.

The standard reliability levels of groups of elements, unlike the standard values of survivability, are not constant. The object is represented as a system, consisting of hierarchically connected groups with the identical bearing elements, for determining the standard levels of reliability. We assume that, human errors committed in one of the groups do not depend on the errors made in other groups. Accordingly, methods of the system reliability theory were used to assess the level of reliability of the mine surface object, [1, 2, 3].

In the further step, we will investigate the dependence of the reliability of the elements on their number.

Data on the physical wear of facilities of the mining enterprises Kryvyi Rih Basin, which were obtained by the employees of the SIHE "Kryvyi Rih National University" at survey of 1000 objects.

Data on physical wear are divided into four groups aimed at demonstrating the physical state separation of the objects under study, as shown in Fig. 2

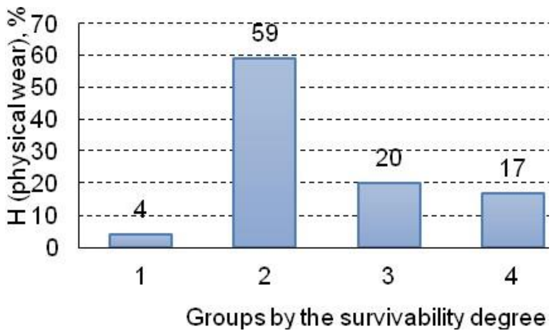

Figure 2. Physical state separation of the objects under study

In fact, the statistics record the defect detection results of identical statistically independent objects. The so-called scheme includes research based on the random censoring. This research is conducted until one of the elements of the object fails. If areas equal to the length of a building or structure are considered as building elements, then the studies are carried out until the first failure at some areas. The complexity of the problem lies in the fact that such areas are neither identical nor statistically independent. However, presentation of the tests through statistical data is possible by renumbering of areas. This problem is solved by using the theory of extremal ordinal statistics.

For practical application, the theoretical curve is divided into four linear sections, at the junction of which the physical wear changes in an abrupt way, as shown in Fig.3. It is known [4] that any change in wear rate informs on a change in the technical state of the mine surface object. Investigations of the object survivability degree of different service life and the subsequent analysis of the research results enabled to determine the position of buttress points (thresholds for survivability).

Consider the mechanical models underlying the theory of crack propagation [1,2]. The destruction of any solid is a time-consuming process and is usually divided into two main stages: the stage of damage development and the stage of crack growth, resulting in disturbing the solidity of the body and its complete destruction in further [3, 4,].

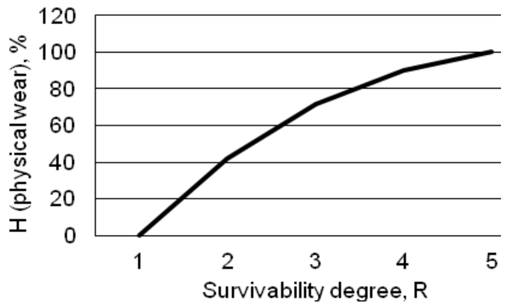

Figure. 3. Degradation model of the supporting carcass of the mine surface object and the threshold values of the survivability

For example, the load mode is set as σ(*t*), where (*t*)is the time.Often, other parameters such as the number of load cycles and even the current deformation value can be used instead (*t*). It is assumed that the loading mode is set as a function of time. According to the damage, its measure M is introduced. Hence, it is offered $0<M<1$, where M is deemed to be equal to one as a condition of destruction. Sometimes it is possible to give a certain physical or mechanical sense to the damage degree. However, it is not necessary when considering the intuitive approach to the destruction.

Study results on structural elements are represented in the form of statistical data. The analysis of the industrial accidents of engineering structure elements of mines shows that almost all of them are due to existing defects. Imperfection or the development of initially existing defects occur as a result of different damage accumulations [5, 6]. One defect is considered to lead to complicated problems. Industrial structures of mines can be attributed to rather complex structures, which represent a sequential system of elements and connections. However, due to the fact that the number of elements is large, it is possible to apply methods of extreme ordinal statistics [7].

As a result, the desired diagram "wearsurvivability " is obtained.

The operating time of the surface object of the mines until a satisfactory degree of survivability R_{sat}=12 (satisfactory) determines T_6 as an upper limit of the safe resource of the surface object of the mines. The technical state of the surface object of the mine at this time interval can be treated as safe. When the object reaches an unsuitable degree of survivability R_{uns}=36 (unusable), wear is more than 60%. With such a wear, a major repair of the building is required [5]. Otherwise, the survivability continues to grow and reaches the next critical value R_{crash}=84 (crash), which determines the marginal resource of the surface object under test.

The survivability degree of the mine surface object depends on the technical condition of the groups of elements that form the entire structure of the facility. The number of such groups, as well as the number of structures in buildings and constructions is large. Determination of actual levels of reliability in the survey of structures is timeconsuming and costly. The quantity of expert works will be drastically reduced if the principles of qualimetry are used as a basis for assessing the technical condition of the bearing framework of the mine surface object. For this purpose, the most and least defective constructions are found in each group, followed by an expert evaluation of their compliance with the project requirements in terms of ensuring their strength, rigidity and stability [6, 7].

The model selection of physical wear of the mine surface object is justified by studies of the resource of structures in the reliability theory [1, 2, 8, 9]. The table given below represents the amount of physical wear of the current facility at time T, at which the technical condition of the mine surface object was diagnosed and the value of its actual degree of survivability R was calculated:

$$\Phi=\Phi(T)=1-\exp(-k(R)) \qquad (1)$$

For the time of commissioning the surface object, taking R=1, we get almost zero value, which is logical. In order to determine the coefficient entering the formula (1), we take the degree of survivability R_{crach}=84. Thus, the physical wear of the mine surface object is 0.80. With these data, it follows from formula (1) that k =0,0193.

This all makes it possible to determine the constructional wear Φ_{limit} (limit). So when the object reaches a satisfactory degree of survivability $R_{sat}=12$, it follows that Φ_{limit}=0,20 (20%). At this amount of wear, repairs of the object should be started. Similarly, when the object reaches an unusable degree of survivability $R_{uns}=36$, it follows that Φ_{limit}=0,50 (50%). At this wear, major repair work of the object should be started urgently.

In the mathematical model (1), the time factor is a registered time point, i. e., the lifetime of the mine surface object at which the technical condition was inspected, the survivability level was calculated and the actual wear of the mine surface object at given time T was determined. In order to forecast the safe residual resource of the mine surface object the dependence of physical wear on time is taken as exponential one:

$$\Phi(T)=1-\exp(-i\cdot T_{factual}), \qquad (2)$$

where i - intensity of physical deterioration of the mine surface.

At $T_{factual}$ the wear is known and is equal to $\Phi=\Phi(T_{\phi})$. By comparing the obtained equations, we can get

$$1-\exp(-kR)=1-\exp(-iT_{factural}); \quad i=\frac{0{,}0193R}{T_{factural}}. \qquad (3)$$

Safe residual resource T_{safe} is determined by the formula $T_{\text{safe}}=T_{\text{permissible}}$, where $T_{\text{permissible}}$- the start time of the surface mine object construction until it reaches the maximum permissible survivability $R_{\text{permissible}}$. Time $T_{\text{permissible}}$ with the intensity is determined from equation, if to take that Φ_{limit}=0,50 or Φ_{limit}=0,20. As a result, the formulas for determining the safe residual life (srl) and the safe resource without a safety overhaul (swro) are the following, respectively:

$$T_{srl}=\frac{0{,}2316}{i}; \quad T_{swro}=\frac{0{,}6562}{i} \qquad (4)$$

According to the formula (4), it is possible to predict the safe resource of the mine surface object at the end of its construction. For this, the value $T_{factual}$ should be equal to zero. At $R_{factual}>R_{permissible}$ the safe resource of the mine surface object is completely exhausted.

The maximum service life of the mine surface object $T_{critical}$ can be predicted from the condition that the wear is known and equal $\Phi_{critical}$=0,80. Time $T_{critical}$ can also be determined from equality:

$$T_{critical}=1{,}66212/i. \qquad (5)$$

The formula (5) is valid if repair and restoration work has not been carried out at the site.

The indicators of the resource essentially depend on the magnitude of the actual survivability during the survey of the object technical state. Exceeding the normal value of survivability of the mine surface object results in decrease in the safe resource of the facility. This fact is illustrated in Fig. 4.

If, repair and restoration works at the site are not carried out by the end of a safe resource, the resistance of its elements under impacts (especially emergency ones) is reduced and may lead to an accident.

For further research, we use the SCAD project-computing complex. The complex implements finite element simulation of static and dynamic design schemes, stability testing, selection of unsuitable combinations of efforts, selection of reinforcement of reinforced concrete structures, testing of the bearing capacity of steel structures.

When the object exceeds the limit of survivability, the growth of information uncertainty slows down, which means the transition of the object to a dangerous state. Such a state can be emergency, when defects appear in bearing structures, and are precursors of the accident. When an object meets the threshold value of vitality, not only the degree of uncertainty of the technical state of the load-bearing framework becomes maximal, but also the magnitude of its structural wear. This means that the object is in a state, when accident becomes unpredictable.

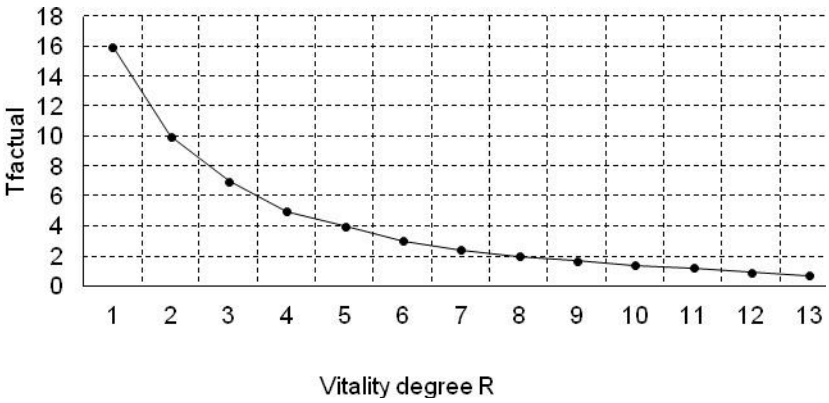

Figure 4. Dependence of an object safe resource on the risk values until the end of the construction

An inclined gallery No. 1, operating at the Volnogorsk Mining and Metallurgical Combine, was taken for calculations. It is one of the transportation sections of minerals to the concentrator.

The design and computing complex SCAD allows to design a three-dimensional model of the inclined gallery and to apply the loads analytically calculated to the beams of the upper and lower belts shown in Fig. 5 The calculation scheme is defined as a system with a sign of 5. This means that we consider a general system whose deformations and its main unknowns are represented by linear displacements of node points along the X, Y, Z axes and rotations around these axes.

The design scheme is characterized by the following parameters:

- number of nodes - 513;
- number of finite elements - 1115;
- total number of unknown movements and turns - 2874;
- number of loads - 12;
- number of combinations of loads - 4

The static calculation of the system is carried out in a linear formulation.

Possible displacements of nodes of the finiteelement computational scheme are limited by external relations, which prevent from some of these displacements.

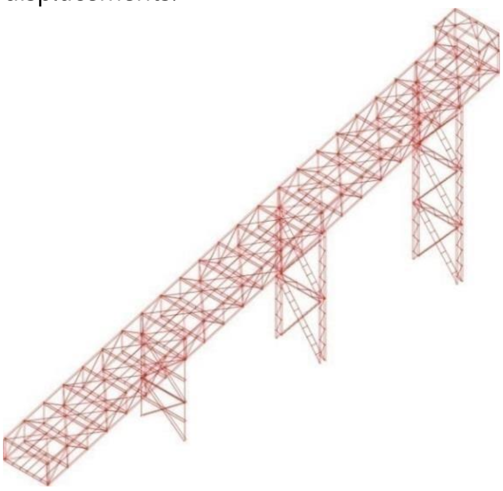

Figure 5. Constructive three-dimensional diagram of the inclined gallery in the design and computing complex SCAD

The gallery was designed in view of atmospheric loads such as snow and a combination of permanent loads on the upper belt of the gallery (waterproofing, cement fiberboard, cement screed, reinforced concrete slabs), on the lower belt (cement fiberboard, reinforced concrete slab, asphalt, leveling layer) and combinations of special loads such as sand under the conveyor belt, payload in the passage and loads from the conveyors.

Based on the obtained results on longitudinal forces in the rods, the deformation of the elements, the diagrams of the normal and lateral forces and the moment, we conclude that the gallery withstands all the loads acting on it and is tested for the sustainability in accordance with the construction norms and rules.

The maximum possible combination of loads from the weight of the structural elements, the action of the conveyors, as well as the atmospheric action was applied on the rod of the upper and lower belts in order to check the inclined gallery for corrosion resistance of ten, twenty, and forty percent.

Based on the results of computer simulation, a diagram of the stress (σ) dependence on the corrosion was displayed. As can be seen from the diagram in Fig. 6, the stresses are directly proportional to the dependence on the corrosion value.

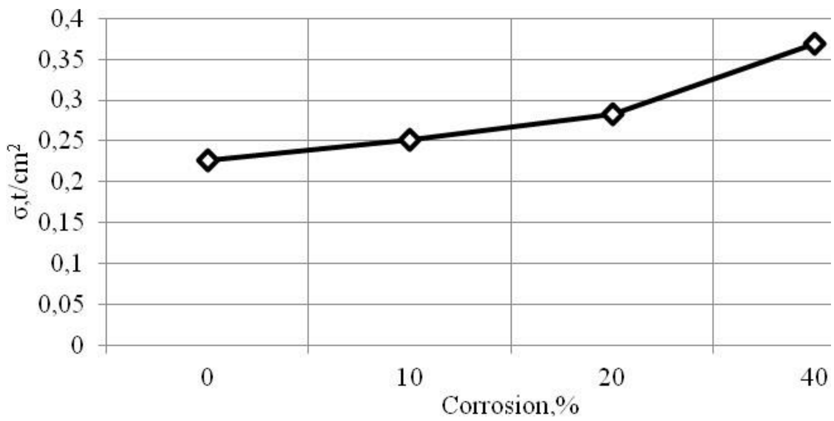

Figure 6. Diagram of the stress (σ) dependence on the corrosion

A sequential system is characterized by the fact that failure of one element causes failure of a system.

The Weibull distribution is natural for the uptime operation of a sequential system, to which one can refer the part of the structural elements under investigation. The task is to find the distribution parameters in each particular case.

The Weibull distribution contains two parameters [8]: the characteristic lifetime (*c*) and the shape parameter (α)

$$W_n(t) = 1 - \exp\left[(-t/c)^{\alpha}\right] \quad (6)$$

If up-time of the element of a sequential system has a Weibull distribution

$$F(t) = 1 - \exp\left[(-t/c)^{\alpha}\right] \quad (7)$$

then the limiting distribution of the system uptime has an exact Weibull distribution, and not asymptotically

$$W_n(t) = 1[1-F(t)]^n = 1-\exp[(-t/c)^{\alpha}] \quad (8)$$

Thus, the shape parameter for the element and the system coincides, and the characteristic time for the system is

$$C_1 - c_n - ^{\frac{1}{\alpha}} \quad (9)$$

If the distribution for the element is not a Weibull distribution, then the distribution of the uptime system tends to the Weibull distribution asymptotically for *n*□□.

The parameter of the shape α can be found from condition

$$\lim_{x\to=0} F(xt)/F(t) = t^{\alpha} \quad (10)$$

We assume that the loads on the various elements can be different. Perhaps it does not allow the use of the model of a sequential system, since the elements of the system are not in identical conditions. Suppose that in the structures (of their elements) the loads vary linearly depending on the number of the element *i* (*i*=1,2...,*n*)

$$p_i = A + i\cdot B;\ A = (n\cdot p_1 - p_n)/(n-1) \quad B = (p_n - p_1)/(n-1) \quad (11)$$

where p_1 and p_n - the initial and final loads in the element. We transform

$$m_k = \int_{0,1} x_k \cdot f_h(x_k)dx_k = k/(n+1) \text{ to the form } pi = A + (n+1)\cdot mi\cdot B \quad (12)$$

where m_i - mathematical expectation *i*-th ordinal statistics for the uniform distribution, defined by the formula.

Consider the set of random variables $p(x_{hi})$, defined by formula

$$p(x_{hi}) = A + (n+1)\cdot m_i \cdot B \quad (13)$$

where x_{hi} - ordinal statistics for uniform distribution.

If we return from the ordinal statistics to the initial set of random variables, then we can assume that a single element as an element of a sequential system is under the influence of a random load

$$p = A + (n+1)\cdot X\cdot B \quad (14)$$

where *X* - a random variable uniformly distributed in the interval (0÷1).

The numbering of elements is not important. In the general case, when the load varies nonlinearly from element to element in accordance with a certain relation

$$p = \phi(x) \quad (15)$$

where the argument *x* changes from zero to one, the procedure for changing from ordinal statistics x_{hi}

$$vp_i = \phi(x_{hi}), \quad (16)$$

The possibility of such a representation can be justified by linearizing the function of a random argument. In this case, the mathematical expectation and dispersion are expressed in the form

$$E[p_i] = E[\varphi(x_{hi})] \approx \varphi[i/(n+1)] \quad (17)$$

The last formula shows that if the function *F*(*t*) sufficiently flat, then the spread of the random variable p_i near its mathematical expectation will be sufficiently small.

It can be said that the element of a sequential system is under a random load

$$p = \phi(n\cdot X) \quad (18)$$

where *x* - a random variable uniformly distributed in the interval (0÷1).

The asymptotic formula for the time distribution function of the uptime element, generalizing the formula for *F*(*t*) gives the Weibull law

$$F(t)=1-\exp[-m(t/T)^{2/3}] \quad (19)$$

where *T*=2/3*As*, s - area under the stress curve at (0÷1).

The statistical data processing is carried out by the Bayesian method [9, 10].

All uncertainty is considered to be concentrated in the parameter *m*. First, this parameter has a priori distribution *h*(*m*). After the receipt of empirical information $I_э$, in our case, it is about study results of the structural elements, a priori distribution changes. The result of the change is a posteriori distribution, which we must determine. Thus, a posteriori distribution of a parameter characterizing the magnitude of a defect is a characteristic of the reliability of studies that form the reliability of engineering structures in operation.

Stage 1 - mapping the plausibility function $R(m/I_э)$. Empirical information is a censored sampling of developments on the failure of elements of engineering structures. A piece of information: *L* - length of the structural element; *D* - cross-sectional area; δ - thickness of the element; *n* - number of elements, length Δ*L* , i.e. *L*=*n*·Δ*L*.

If in the process of operation (research) there was a failure, then this information is of the 1st type. Time t_1 - the moment of failure, the lifetimes of other elements are censored.

If the failure does not occur (information of the 2nd type) and the technological operation is over, i.e., it is stopped, then the lifetimes of all elements are censored.

Taking into account the form of the distribution function $F(t)$, the plausibility function for the 1st type information has the form

$$R(m/l_э)=2/3mt_1^{-\frac{1}{3}}\cdot T^{\frac{2}{3}}\exp\left[-mn\left(t_T/T\right)\right]^{\frac{2}{2}} \quad (20)$$
$$T=2\delta/(3As);\ s=\int_{0,1}\sigma(nx)dx$$

The plausibility function for the 2nd type information has the form

$$R(m/l_э)=\exp\left[-mn(t_2/T)\right]^{\frac{2}{3}} \quad (21)$$

With the sequential receipt of information, the general plausibility function is the difference of the plausibility functions for each piece of information.

Stage 2 - determination of a posteriori density $h_1(m/l_э)$. If a priori distribution $h(m)$ is a gamma distribution and a plausibility function $R(m/l_э)$, then a posterior distribution $h_1(m/l_э)$ is also a gamma distribution $h_1(m/l_э)$

$$h_1(m/1_э)=m^{r-1}v^r\exp(-vm)/\Gamma m) \quad (22)$$

the parameters r and v are calculated according to the following rules:

For information of type I

$$\Rightarrow r=q+1;\ v=n(t_1/T)^{\frac{2}{3}} \quad (23)$$

For information of type 2

$$\Rightarrow r=q;\ v=z+n(t_2/T)^{\frac{2}{3}} \quad (24)$$

Stage 3 - point estimation m_0. Point estimation m_0 is a posteriori mathematical expectation

$$m_O=m_{апост}=r/v \quad (25)$$

for information of type 1

$$\Rightarrow m_o=(q+1)\left[z+n(t_1/T)\right]^{-1} \quad (26)$$

for information of type 2

$$\Rightarrow m_0=q\left[z+n(t_2/T)^{\frac{2}{3}}\right]^{-1} \quad (27)$$

Stage 4 - determination of the upper pconfidence boundary of the parameter m such that

$$P\{m<m_p\}=p. \quad (28)$$

Since a posterior distribution $h_1(m/l_э)$ is a gamma distribution, in this case it is possible to obtain the formula for m_p

$$m_p=\chi^2_{p:2r}/2v \quad (29)$$

where $\chi^2_{p:2r}$ - quantile of probability p for distribution.

Assuming that the constructive element of the sequential system is under random load p=□(n□x), where n - the number of elements, x - a random variable uniformly distributed in the interval (0÷1), the asymptotic formula for the distribution function of the uptime of the element can be determined

$$F(t)=1-\exp(-mK^{2/3})$$

where K - coefficient, depending on the design parameters of the element.

The study of structural elements is presented as a study of a system of constructive elements, each of which has a function for distributing uptime. Processing of statistical data can be performed using the Bayesian method: all uncertainty is concentrated in the parameter. This parameter has an a priori distribution. After the receipt of empirical information, in our case it is the research results on the elements of an industrial structure, the a priori distribution changes. Thus, a posteriori distribution of the parameter characterizing the magnitude of the defect is a characteristic of the reliability of work performance in the reconstruction of an industrial structure m_p, forming the operational reliability of the entire system.

The value m_p is a reliability indicator of the technological operation to study the element for strength. The smaller m_p, the worse the set of technological operations to study this element, i.e. an increase in the parameter indicates a higher level of operational reliability of the entire system of elements. The paper shows how the parameter m_p varies depending on the division of the system into study areas.

Conclusions. Based on the results of studies and calculations, the following conclusions can be drawn: The standard values of the survivability are constant, since they do not depend on either the structural type of the building or its storeys. They form the lower and upper boundaries of acceptable values of the object's survivability. If the actual survivability is within these boundaries, the facility safety should be considered satisfactory. The design provides the necessary stability for safe operation at ten and twenty percent of corrosion. However, at forty percent of corrosion, lateral braces of the second and third trusses, as well as the fixed support between the first and second farms, do not meet the stipulated design standards for safe operation and lose their stability. The use of modern software enables to compute the better calculations for a steel frame, since many parameters are neglected in the non-computing calculation methods. The use of a lighter material as an overlapping of the upper belt of the gallery makes it possible to remove a significant load. Without additional means to combat corrosion at more than twenty percent, the gallery constructions lose their bearing capacity.

The paper considers a mechanical model for the defect propagation under conditions of a stressed state of a structural element. Experimental data on the study of structural elements of industrial objects in mines made it possible to determine the parameters of the kinetic equation using the principles of the regression analysis. It made possible to obtain a dependence characterizing the time interval before the destruction of a defect at different values of the acting or arising loads. The performed calculations suggest that the detection of a defect is dependent more on the magnitude of the initial defect than on the magnitude of the load.

The threshold values of survivability are determined, at which the mine surface object passes to a qualitatively different state - from normal to satisfactory, from satisfactory to unsuitable, and from unsuitable to emergency.

The proposed methodology for assessing the safety of operating facilities can be used in practice to assess the degree of survivability, a type of technical condition and a safe residual resource.

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