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QUALIMETRIC ASSESSMENT IN CALCULATION OF THE SURVIVABILITY LEVEL OF THE MINE SURFACE OBJECTS

Purpose. Development of a qualimetric assessment as one of the methods for determining the technical condition of the structural elements of surface mining objects, which allows for minimum correction in reliability levels and ensures the highest safety standards of the mine facilities.

Methodology. The methods of expert qualimetry and probabilistic-statistical qualimetry are applied in the study. The former case represents the estimates which are given by experts or automated expert systems, while the latter case uses the methods of probability theory and mathematical statistics for assessing the homogeneity of the identification of the respective values and the coincidence of the distribution laws.

Findings. The law on condition of the operated facility as a dependency of the building supporting structures on its survivability has been modeled. The threshold values of survivability have been determined, at which the mine surface object passes into a qualitatively different state – from normal to satisfactory, from satisfactory to unusable, and from unusable to emergency.

Originality. The scientific novelty of the method proposed is an adequate description of the technical condition of the facility structural elements, which takes its place among the new modern experimental studies on materials and structures of the surface objects.

Practical value. The qualimetric assessment method allows determining the object survivability at some point, the technical condition and the safe residual resource. The above-mentioned activities have resulted in significant improvements in reliability of the operated facilities, hence, preservation of both tangible assets and lives of an enterprise's employees.

Keywords: *mine surface objects, reliability, survivability, qualimetric assessment*

Introduction. Industrial surface objects at a mining enterprise are considered as a complex construction, representing an organized set of the identical constructions similar to foundation, walls, overlap, and so on. 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.

Unsolved aspects of the problem. Modern science and production are based on the standard methods for determining the current condition of the structural elements. The standard values of the survivability include the following:

- normal survivability, which regulates the survivability value of the object after completion of construction work;
- satisfactory survivability, at which the mine surface object passes from the normal to the satisfactory condition. Repair works on the object are required;
- unusable survivability, at which the object passes from the satisfactory to the unusable condition. The ability of the object to resist the loads acting on it decreases. Repair and restoration works are required;
- emergency survivability (crash), at which the mine surface object passes from the unusable condition to the emergency one. The ability of the object to resist the loads acting on it decreases and operation is strictly prohibited. At a time, the development and implementation of new techniques on a comprehensive determination of the current condition of the surface objects prolongs their safe operation.

Analysis of the research and publications. The works of scientists V. V. Bolotin, A. R. Rzhanitsyn, A. G. Roitman, V. D. Raiser contributed to the development of methods of reliability theory in construction.

In the view of A. R. Rzhanitsyn, there are limited possibilities of the mathematical apparatus with respect to solving many problems encountered in engineering practice. There are few generalizing methods for problems of reliability and probabilistic calculation of building structures.

Bolotin V. V. in his works refers to the issue on forecasting the individual resource of structures based on the observation results of their condition in the operation.

Raiser V. D. argues that at the present time regarding the normalization of the rules for calculating building structures, a designer knows almost nothing about how successfully he or she fulfilled his/her main task – project support for the normal functioning of the structure.

Klevtsov V. A. and Kuzevanov D. V. believe that reliability is only declared, and the designer, having carried out the calculation, does not have a strict idea about the results of their work, the reliability and reserves of the design created by them.

Holicky M., Diamantidis D., Sykora M., Johan V. Retief, Celeste V. [1, 2] define modern criteria for designing structures that provide a wide range of reliability indicators for different base periods of existence of objects, even if their calculation for different base periods is uncertain through the interdependence of failures. General approaches to the choice of reliability levels are discussed from the point of view of optimizing costs and human security. The target effects of cost reduction and the consequences of failures on security measures are considered. The issues of bridging the gap between probabilistic and operational evaluation at design are addressed. It was suggested that improved reliability principles and models could contribute to further development of international standardization of construction [3, 4]. The works of K. M. Chaminda Konthesinghaa, Mark G. Stewarta, Paraic Ryana, John Gingerb, David Hendersonb [5] are devoted to the development of a vulnerability model for predicting the probability and damage degree to metal lining of industrial buildings under extreme wind loads. The model uses structural reliability methods to describe the spatial distribution of wind load. In the work "Research on Industrial Building's Reliability Assessment Based on Projection Pursuit Model" Zhang Lei and Jie Liu presented a model of industrial building reliability based on the classification of observation results. Optimum values are obtained using the composite simplex method. The 3 factors, selected as a system of evaluation indicators, were identified from 11 which affected the reliability of the industrial building.

Practice shows that when assessing the condition and operation of buildings and structures, it is necessary to take into account:

- conventionality of the static design schemes and possible deviations of the forces from their actual distribution in the structures;
- conventionality of the applied design characteristics of materials;
- possible deviations of loads from calculated values;
- a random nature of the actual influence from outside.

It is often impossible to assess the influence of the whole range of the listed factors theoretically. Modern experimental studies on materials and building structures are therefore of heightened relevance.

Previously unsolved part of the general problem. The technical condition of the structural elements of buildings is assessed by comparing the maximum permissible (calculated or normative) and actual values characterizing strength, stability, deformability and performance of structures.

The properties of building materials, bases, loads and impacts, operating conditions are the determining factors when assessing the technical condition of a surface object. The method of limit states as a basis for calculating structures takes into account a statistical nature of the indicators in calculation, as well as an impact of various operational factors through the appropriate reliability factors. The limit states method is a semi-qualitative method for calculating reliability. It includes the probabilistic methods for normalizing the strength of materials, operating loads and reliability coefficients, and the strength is calculated in a deterministic form. Therefore, the method of limit states does not allow for a comprehensive understanding of the survivability of the operated object.

Objectives of the article. The main methods for determining the object survivability can be distinguished as:

- technical;
- organoleptic;
- calculated.

A qualimetric assessment used for calculating the survivability of the surface object, that meets all the security requirements, ensures an accident-free operation.

The use of the qualimetric assessment methods entails high-quality performance, minimizes correction in reliability levels and ensures high safety standard of the mine facilities.

Presentation of the main research. Unlike the standard survivability values, the standard reliability levels of elements groups are not constant. In order to determine the standard reliability level, an object is considered as a system of hierarchically and serially connected groups of the identical bearing elements. We assume that human errors committed in one of the groups do not depend on the errors made in other groups. Hence, we apply methods of the system reliability theory [1, 2], in order to assess the reliability of the mine surface object. The result is

$$\nu = \prod p_n, \quad (1)$$

where $\prod p_n$ is the work of the reliability levels of all groups of object elements.

To determine the average value of the survivability level we should use the ratio resulting from (1)

$$R = \frac{1}{M_\nu}, \quad (2)$$

where M_ν is the average value (mathematical expectation) of a random variable, the numerical values of which range from 0 to 1.

The analogy between the destruction of the elements and signals about their destruction is based on the following statistical positions.

Let there be a set of links between elements of a given strength $R_1, R_2, \ldots, R_i, R_m$, whose probabilities are not equal and presented as $P_1, P_2, \ldots, P_i, P_m$.

As a result of the external load action, we can get the combination of the destructed links that contains an n set of m links. Among them, let it be n_1 links P_1, n_2 links P_2, n_n links P_n. The probability of each link is determined by $P_i = \frac{n_i}{n}$.

All destructed links would be based on the complete system of unplanned (accidental) events

$$\sum_{i=1}^{m} P_i = 1. \quad (3)$$

Further, from formula (2, 3), in view of the relation (1) it follows that the average survivability of the surface mine object is

$$R = \frac{1}{M_v} = \frac{1}{\prod p_n}. \quad (4)$$

We suppose that in all n element groups of the mine surface object, the average reliability levels $p_{n,\ averaged}$ are the same and equal to p_n. In this case, the average survivability of the building by definition is expected to be equal to the normal value R_p, and formula (4) takes the form of $R_p = \frac{1}{p_p^n}$ which determines the normal, satisfactory, and limit level of structural elements. This has resulted in

$$p_p = \sqrt[n]{1/R_p}; \quad p_б = \sqrt[n]{1/R_б}; \quad p_ї = \sqrt[n]{1/R_ї}. \quad (5)$$

We use data on the physical wear of industrial objects of the Kryvbas mining enterprises, which were obtained by the employees of the Kryvyi Rih National University at survey of over 1000 objects.

The data on physical wear of the objects under study are divided into four groups and visually represented in Fig. 1.

For practical application, the theoretical curve shown in Fig. 2 is divided into four linear sections, at the junction of which the physical wear varies discontinuously. It is known [4] that any change in the rate of wear indicates the change in the technical condition of the mine surface object. Investigations of the object survivability of different service life and the subsequent analysis of the study results served to define the location of the joint points (threshold values of survivability levels).

To achieve the desired "wear-survivability" diagram, we determine the reliability levels by formula (5).

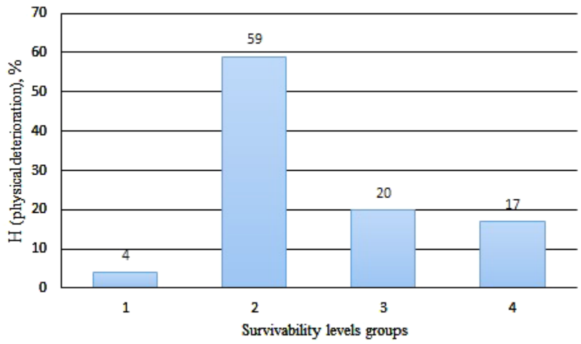

Fig. 1. Four groups of the object physical condition:

1 – normal survivability; 2 – satisfactory survivability; 3 – unusable survivability; 4 – emergency survivability

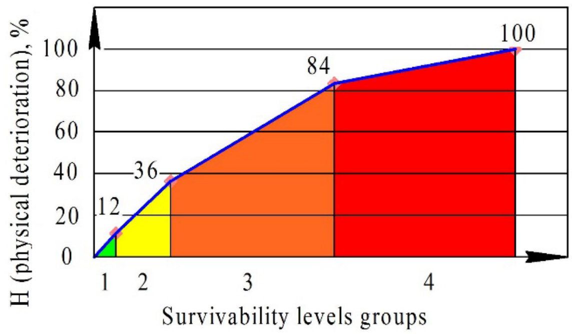

Fig. 2. Degradation model of the supporting carcass of the mine surface object and the survivability threshold values:

1 – normal survivability; 2 – satisfactory survivability; 3 – unusable survivability; 4 – emergency survivability

The operating time of the surface object until a satisfactory survivability $R_{sat} = 12$ determines T_b as an upper limit of the safe resource of the object. The technical state of the surface object of the mine at this time interval can be referred to as safe. When the object reaches an unusable survivability $R_{uns} = 36$, the wear is more than 60 %. At such a wear rate, repair works of the building are required [5]. Otherwise, the survivability continues to grow and reaches the next critical value $R_{crash} = 84$, 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 are large. Determination of actual levels of the reliability at survey of structures is time-consuming and costly. The quantity of expert works will drastically reduce 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 [8, 9]. The table given below represents the value of physical wear Φ 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 survivability R was calculated

$$\Phi = \Phi(T) = 1 - \exp(-k(R)). \quad (6)$$

At the time of commissioning of mine surface object, taking $R = 1$ we get almost zero, and that is logical. In order to determine the coefficient k entering the formula (6), we take the degree of survivability $R_{crash} = 84$. Thus, the physical wear of the mine surface object is 0.80. With these data, it follows from formula (6) that $k = 0.0193$.

This all makes it possible to determine the constructional wear Φ_{limit}(limit). Thus, when the object reaches a satisfactory survivability $R_{sat} = 12$, it follows that $\Phi_{limit} = 0.20$ (20 %). With such a value of wear, the repairs of the object should be initiated. Similarly, when the object reaches survivability level $R_{uns} = 36$, it follows that $\Phi_{limit} = 0.50$ (50 %). With such a value of wear, capital repairs of the object should be initiated urgently [10, 11].

In the mathematical model (6), the time factor is a registered time point $T_{factual}$, 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 Φ of the mine surface object at given time T was determined [12]. In order to predict the safe residual resource of the mine surface object the dependence of physical wear on time is taken as exponential one

$$\Phi(T) = 1 - \exp(-i \cdot T_{factual}), \quad (7)$$

where i is the intensity of the physical deterioration of the mine surface object. At $T_{factual}$ the wear is known and is equal to $\Phi = \Phi(T_f)$. By comparing the obtained equations, we can get (6, 7)

$$1 - \exp(-kR) = 1 - \exp(-iT_{factual}); \quad i = \frac{0.0193R}{T_{factual}}. \quad (8)$$

Safe residual resource T_{safe} is determined by the formula $T_{safe} = T_{permissible}$ where $T_{permissible}$ is the start time of the surface mine object construction until it reaches the maximum permissible survivability $R_{permissible}$. The time $T_{permissible}$ with the intensity is determined from equation, if to take that (8), if to take that $\Phi_{limit} = 0.50$ and $\Phi_{limit} = 0.20$. 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

$$T_{srl} = \frac{0.2316}{i}; \qquad T_{swro} = \frac{0.6562}{i}. \quad (9)$$

According to the formula (9) we can 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. When $R_{factual} > R_{permissible}$ the safe resource of the mine surface object is completely exhausted [13, 14].

The maximum service life of the mine surface object $T_{critical}$ can be predicted from the condition that the wear

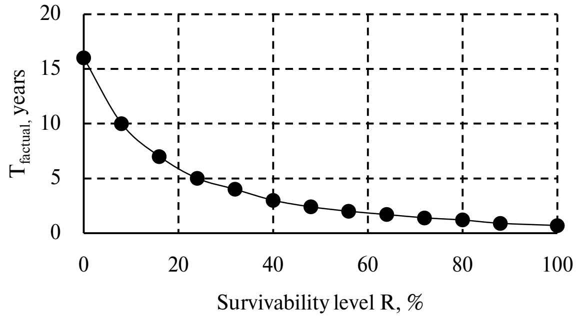

Fig. 3. Dependence of an object safe resource on the risk values until the end of the construction

rate is known and equals $\Phi_{critical} = 0.80$. Here, time $T_{critical}$ can also be determined from the equation

$$T_{critical} = 1.6212/_{3}. \quad (10)$$

Formula (10) is valid if repair and restoration work has not been carried out at the site [15].

The resource indicators essentially depend on the actual survivability at survey of the object technical condition. The excess of the normal value of survivability of mine surface object reduces the safe resource. This fact is illustrated in Fig. 3.

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.

Conclusions and recommendations for further research. The law model of the technical condition of the operated facility as a dependency of the supporting structures on its survivability is obtained. Thus, a safe resource is determined when the resistance of the elements to effects (especially emergency ones) does not decrease and further operation of the facility is possible.

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

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

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Кваліметрична оцінка при розрахунку ступеня живучості промислових об'єктів на поверхні шахт

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Мета. Створення одного з методів оцінки технічного стану елементів конструкцій будівель і споруд поверхні шахт – кваліметричної оцінки, що дозволяє звести до мінімуму коригування рівнів надійності, та встановити високий рівень безпеки об'єктів поверхні шахт.

Методика. При проведенні досліджень застосовані методи експертної та ймовірносно-статистичної кваліметрії. У першому випадку оцінки даються експертами або автоматизованими експертними системами, а у другому – використовуються методи теорії ймовірностей і математичної статистики, оцінюючи однорідність сукупності вибірок і збіг законів розподілу.

Результати. Отримана модель, що дозволяє визначити стан будівлі, що експлуатується, у вигляді залежності зносу несучих конструкцій об'єкту від величини його рівня живучості. Визначені порогові значення ступенів живучості, при досягненні яких об'єкт поверхні шахт переходить до якісно іншого стану – з нормального в задовільний, задовільного в непридатний, а з непридатного в аварійний.

Наукова новизна. Наукова новизна запропонованого в роботі методу – адекватний опис технічного стану елементів конструкцій будівель і споруд поверхні шахт, що займе свою нішу серед нових сучасних експериментальних досліджень матеріалів і конструкцій об'єктів поверхні.

Практична значимість. Створення методу кваліметричної оцінки дозволяє визначати ступінь живучості об'єкта на певний момент часу, вид технічного стану й безпечний залишковий ресурс. У результаті проведення запропонованих заходів підвищується рівень безпеки промислового об'єкта, що тягне за собою збереження як матеріальних активів, так і життя працівників підприємства.

Ключові слова: *об'єкти поверхні шахт, надійність, живучість, кваліметрична оцінка*

Квалиметрическая оценка при расчете степени живучести промышленных объектов на поверхности шахт

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Цель. Создание одного из методов оценки технического состояния элементов конструкций зданий и сооружений поверхности шахт – квалиметрической оценки, позволяющий свести к минимуму корректировки уровней надежности, а также установить высокий уровень безопасности объектов поверхности шахт.

Методика. При проведении исследований применены методы экспертной квалиметрии и вероятностно-статистической квалиметрии. В первом случае оценки даются экспертами или автоматизированными экспертными системами, а во втором используются методы теории вероятностей и математической статистики, оценивая однородность совокупности выборок и совпадение законов распределения.

Результаты. Получена модель, позволяющая определить состояние эксплуатируемого здания, в виде зависимости износа несущих конструкций здания от величины его степени живучести. Определены пороговые значения степени живучести, при достижении которых объект поверхности шахт переходит в качественно иное состояние – из нормального в удовлетворительное, из удовлетворительного в непригодное, а из непригодного в аварийное.

Научная новизна. Научная новизна предложенного в работе метода – адекватное описание технического состояния элементов конструкций зданий и сооружений поверхности шахт. Метод займет свою нишу среди новых современных экспериментальных исследований материалов и конструкций объектов поверхности.

Практическая значимость. Создание метода квалиметрической оценки позволяет определять степень живучести объекта на определенный момент времени, вид технического состояния и безопасный остаточный ресурс. В результате проведения предложенных мероприятий повышается уровень безопасности эксплуатируемого объекта, что влечет за собой сохранение как материальных активов, так и жизни работников предприятия.

Ключевые слова: *объекты поверхности шахт, надежность, живучесть, квалиметрическая оценка*

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