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STABILITY PROBLEMS OF LARGE SIZED MULTI ELEMENTS ROD STRUCTURES

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Abstract

Recently, process of complicating buildings and structures, which is so-called "architectural trend", as well as market competition leads to the construction of insufficiently approved structure forms. The situation is aggravated by the "lagging behind" regulatory framework, unsatisfactory skills of the construction process participants, contravention of the constructed objects operation rules and other negative factors, on the one hand. On the other hand, a number of documents are of a recommendatory nature. Thus, current above-described situation determined the relevance of this publication. There were made the following in order to correctly predict the trouble-free operation of multi-element metal structures:

- concepts, principles, qualitative and quantitative indicators of operational efficiency (survivability) and its categories related to nodes, structural elements and technical systems in general were formulated;

- a large-scale effect both in the designing and in the operation of large-sized and multi-element metal structures was considered;
- emergency metal structures destruction data were analyzed;
- reasons for characteristic defects and rod metal structures damage are considered, including the modeling of damage formation processes, the identification of random physical regularities of the sizes scattering and defects location.

Introduction

The ultimate goal of designing building structures is to ensure their reliability during construction and operation.

The behavior of building structures during their operation is mainly random. Modern standards of the building structures design take into account the probabilistic nature of loads and bearing capacity only in terms of processing the initial data. Limit states method, which is put down in the current design regulations, is semi-probabilistic. Thus, the designing structure reliability is ensured using the specific safety factors: safety factors for loads, for materials, operating conditions factors, reliability factors according to purpose and these values do not have sufficient theoretical and experimental substantiation.

At structures design according to existing standards the actual level of their reliability remains unknown. Modern regulations allow to design structures with a sufficient level of safety in most cases, what is confirmed by the long-term practice of their operation [1,2]. However, in some cases, structures reliability level can be overestimated, and causes excessive materials consumption, or it can be insufficient (rarely), which leads to unnecessary expenses for eliminating the failures consequences during operation.

The building structures calculation, reflecting their real operation behavior, should be fully based on the theory of reliability, based on probabilistic methods, which allow to give a more objective assessment of the normal operation structure suitability. The reliability theory methods provide a theoretical basis for the correct organization of the collecting and processing statistical data related to the effects on a structure, materials characteristics and its structures and other design parameters. These methods most accurately reflect the design values randomness and the relationship between external influences and structure strength.

The main obstacle in the development of the building structures reliability theory at the present time is the absence or insufficient development of probabilistic methods for assessing the complex multi-element systems reliability, which are designed buildings and structures. This is related to the building structures features: the complexity of deterministic solutions, their high reliability and complex relationships between elements. All this leads to methodological and mathematical issues [3,4].

1. Basic concepts, principles, qualitative and quantitative indicators of the operational efficiency of technical systems

The human society activity is inextricably connected with the creation of various technical systems (machines and mechanisms, buildings and structures). United by purpose and organizational structure they create the so-called organizational and technical systems, for example, geotechnical, environmental, economic systems, etc.

Technical systems are characterized by qualitative and quantitative features. The quantitative features include such features as "small", "medium", "large", the qualitative ones - "simple", "complex", "supercomplex" (Fig. 1).

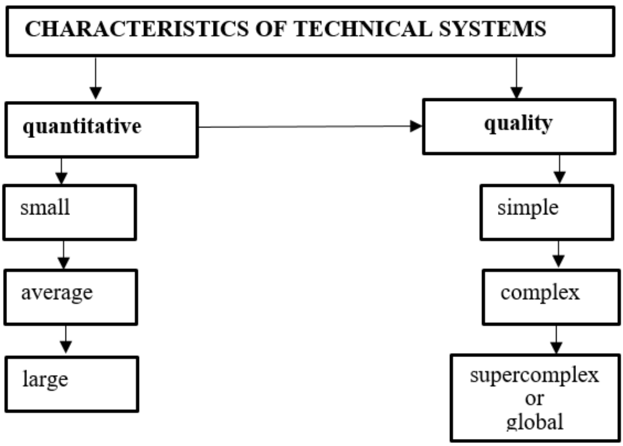

Fig. 1. Technical systems' characteristics

There is a close relationship between quantitative and qualitative characteristics.

Quantitative characteristics are more related to the geometric systems dimensions and number of homogeneous structure elements included. They can be divided into:

- small $a \cdot 10^0$ of maximum indivisible smallest sizes elements;
- average $a \cdot 10^1$;
- large $a \cdot 10^2$,

where a - is a maximum indivisible smallest sizes element of structure.

Qualitative characteristics are more related to the system structure in general, its levels number and complex mostly nonlinear relationships between them.

Systems can be divided into simple, complex and supercomplex (or global) depending on the complexity technical.

Simple systems are one level systems with a minimum number of components and connections between them, when their initial parameters are known. The study and description of such systems does not cause difficulties due to the small number of variables, and the possible states of these systems consequently.

Complex systems consist of several levels, they are distinguished by an increased number of components and connections between them, possible incompleteness of the initial information. The study and description of such systems causes certain difficulties due to the large number of variables. Additional external influences also appear and this leads to increasing the number of these systems possible states.

Supercomplex or global systems are multilevel and multicomponent systems with a big number of connections and a complex heterogeneous structure. Such systems are usually multi-parameter. Initial information about them is often incomplete. Their study and description cause serious difficulties due to a wide variety of external influences and their probabilistic nature, and due to additionally arising internal factors, consequently, which leads to the increase of these systems' possible states number. They have well developed communications and are automatically equipped. As they develop, their sensitivity to various external damaging influences increases.

Damaging impacts can be emergency and catastrophic and the difference between them depends on only these damages scale and consequences.

Catastrophic cases are phenomena which appear in multiparameter dynamic, nonlinearly developing systems (natural, technical, humanitarian), when under the influence of slowly accumulating quantitative changes in control parameters they suddenly lose stability and enter a different qualitative state. This state is characterized by a new information field. Control parameters of complex structures mean time-varying external influences (force influence, chemical, radiation, etc.) on system and its internal (physical) properties [5].

Failure (destruction) of one or several system's elements does not mean the stopping system functioning. Therefore, the "survivability" concept is now widely used [6-9]. That means the property of a structure to maintain its overall bearing capacity in case of local destructions.

N. Streletskyi was one of the first who mentioned the problem of survivability in construction [10]. In the future, the survivability concept was introduced by V. Bolotin [11] and G. Geniiev [12]. At present, building structures survivability problems are considered in the works of A. Perelmuter [7,8], V. Kuliabko[13], Yu.Kudyshyn, D. Drobot [9,14] etc. The "survivability" concept was established in the construction regulations of Ukraine in 2009 (DBN B.1.2-14: 2009).

Generally, the survivability (stability) of load-bearing structures is their ability to keep the operation capacity for a given time in the presence of developing defects and various damages. Survivability sources are the following: physical and mechanical properties of materials, their destruction resist ability; strength reserves, which determine the stress-strain state and the degradation intensity; structural redundancy and element redundancy.

"Progressive" (or "avalanche-like") destruction is meant a fairly rapid "consistent destruction of bearing structures and bases, which leads to the collapse of the entire structure or its parts" [15,16].

There are design, maximum design and beyond design loads.

Design loads are impacts which are established by the current technical regulations.

Maximum design loads are impacts for which initial events and final states are defined, safety systems are provided. These loads consequences can be as much as possible, but within the limits established by the project.

Beyond project loads are the impacts caused by unaccounted initial events, erroneous staff decisions. These loads cause additional failures of system elements.

In construction design regulations and standards for checking metal structures strength the elasticity condition for nominal stresses is used (condition of no achieving plastic deformations according to Mises or Saint-Venan) as well as the strength criterion which limits the absolute values of main stresses by the yield strength limit. The influence of defects and stress concentrators on the strength and durability of structures is not considered. The bearing capacity reduction due to the development of macro-cracks caused by defects is not taken into account. It means that the concept of "no damages operation" is implicitly included in the technical regulations and according to it there should not be cracks in the design sections during the total service life of the structure, including fatigue cracks [17, 18]. But the requirement of total zero defectiveness of metal and welded joints of building metal structures is not provided by modern non-destructive testing techniques. Such structures are operated with the presence of cracks, due to inaccurate calculated determination of the fatigue cracks and fragile cracks appearance moment as well. Moreover, there are defects and cracks of limiting dimensions which do not reduce the strength of metal structures elements [19]. The construction regulations' calculation methods make it difficult to determine the durability, structural safety and survivability of metal structures, because they do not take into account clearly the time factor as the main parameter in the calculations according to the limit states [20].

2.The concept of reliability and durability of multi-element bar structures. Scale effect

The fundamental aspects of materials destruction over the past decades have been sufficiently investigated for simple idealized force schemes [11], but the process of real structures destruction is more complex and requires the study of the stress-strain state under specific operating conditions, taking into account all the destruction mechanisms factors. Thus, there is a need to evaluate mechanisms, structures, technological processes and other technical systems based on their operation stability and reliability.

The answer has been found in the mathematical concept of reliability, in which reliability is considered as the probability of a trouble-free operation of a technical object.

Object reliability is a property of this object to perform its functions in a given mode for a given period of time with a given probability. A quantitative reliability assessment is the object probability to realize its functions - "P".

The reliability concept is inextricably related with the durability concept. Durability is the property to maintain performance for a certain time T. The difference between reliability and durability is in the following: in the first case probability P is determined, time T is a parameter, and in the second case the time T is determined at a given probability R.

The failure concept is associated with the concept of reliability and durability. Failure is a random event corresponds to the object operation capacity trouble. The failure probability is determined by the value

$$q=1-P.$$

There are many classifications of failure types. The most interesting and important classification for building structures has two categories:

- sudden failure;
- gradual failure.

Sudden failure is a failure (in fact, local or global stability loss), characterized by an abrupt changing values of one or more object's parameters.

Gradual failure is a failure resulting from values gradual change of one or more object's parameters. Gradual failure can finally cause the sudden failure, for example, structure failure as a result of the fatigue damages accumulation.

It should be taken into account that on the set of reliability failure conditions of structure, the durability states can be defined and its further sufficient operation efficiency is possible at these states (Fig. 2).

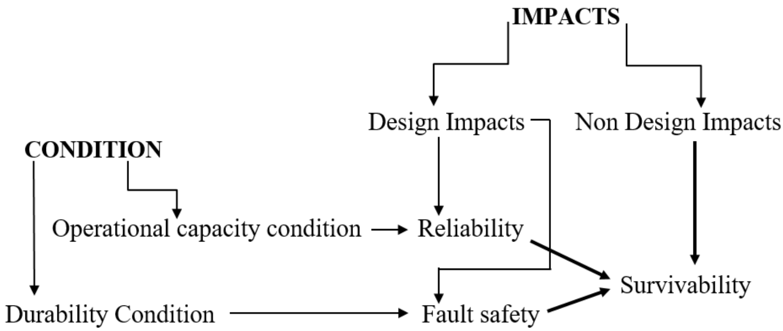

Fig. 2. Differentiation of the reliability and survivability properties depending on the system state

Fail safety is an indicator of the survivability property at normal operation. Durability, including the fail-safety concept is the system survivability in before critical operation area under the external nonregulated influences [14,21].

All technical objects are complex systems consisting of many elements. There are systems with a series elements connection, parallel elements connection and mixed elements connection.

A system with a series elements connection is a system when different elements failures are independent of each other, and the failure of one element at least leads to the failure of the entire system. The reliability of such a system is defined as the probability of failure-free operation of all its elements. If we have a system S, consistyв of n independent elements and the reliability of the i-th element is P_i, then according to the probability theory the reliability of the entire system is determined using the formula

$$P_s = P_1 \cdot P_2 \cdots P_n$$

It should be noted that the system reliability in the case of a series elements connection is less than the reliability of any individual element.

A parallel elements connection system is a system whose elements duplicate each other, and the failure of one of them does not cause the failure of the entire system. For example, let us consider a rope made of parallel wires. In this case the system remains operation capacity as long as at least one element is functioning, that means one wire at least.

The reliability of the system S, consisting of *n* parallel elements with the reliability P_i, where i is the element number, is determined as follows.The system *S* reliability, which consists of *n* parallel elements with a reliability P_i, where *i* - is the element number, is determined in the following way.

Probability of the *i*-th element failure

$$q_i=1-P_i$$

Probability of all elements simultaneous failure

$$q_s = q_1 \cdot q_2 \cdots q_n$$

Therefore, the system reliability is

$$P_s = 1 - q_s = 1 - q_1 \cdot q_2 \cdots q_n$$

can be seen from this formula that at parallel elements connection the system reliability is higher than the reliability of any of the individual elements.

In fact, as a rule, if one of the parallel elements fails, the reliability of the system’s remaining elements decreases. In addition, building structures are multi-element systems with a mixed elements connection, that must be taken into account at reliability calculation.

It should be noted that as technical systems develop a scale effect assessment becomes more and more important. This is another dangerous and unpredictable factor leading to the destruction of multi-element structures.

The scale effect phenomenology is the following: any materials strength decreases when the sizes of these materials products or samples increase.

In 1938 based on statistical data Weibull suggested, that the causes of the scale effect are critical size internal defects, which become more probable in big size samples.

Regarding the technical systems, the following types of scale effect can be distinguished: volumetric type, areal type and linear type.

Volumetric scale effect is more characteristic for the geomechanical systems. Concerning this direction there are numerous studies by M. Protodiakonov, M. Koifman, S. Chyrkov, O. Shashenko [22] and other scientists. Analyzing the results of his own experiments and others known in the literature, M.Koifman proposed to distinguish the following scale effects at determinating the rocks strength:

- first kind scale effect or volumetric scale effect, associated with the structural heterogeneity of the tested material and the presence of defects randomly distributed over the volume;
- second kind scale effect or surface scale effect, associated with the quality of the samples processing and a surface layer destruction degree.

At transfering from a sample to an array the volumetric scale effect is the main, according to M. Koifman.

The areal scale effect associated with the samples transverse dimensions is characterized for the mechanical engineering and metallurgy, aircraft engineering and shipbuilding [23]. Extensive studies on the relationship between the metals strength characteristics and the sizes of tested samples are contained in the work of B. Chechulin [24]. S. Serensen and V. Kogaiev using the "weakest link" theory and the Weibull distribution function described the scale effect taking into account the nonuniform stresses distribution in the body intersection [25].

Regarding the action of variable loads, it was found that the fatigue limit decrease of samples and details at their dimensions increase has two aspects: metallurgical and mechanical. In the first case the large-scale effect is caused by the relatively high degree of material structure imperfection in large castings or forgings used for the manufacturing large-sized details. In the second case the scale effect appears at strength decrease of geometrically similar samples with their absolute dimensions increase and when these samples are cut from the same body [26].

In modern construction many structures consist of bar elements which have length which is much greater than the transverse dimensions, therefore, a linear scale effect is characteristic for bar structures especially. The linear scale effect is the least studied, although it can be observed in rod structures: bridges, overpasses, mine headframes, masts, trusses, cable-stayed rod and mixed systems, large-span structures of stadiums. There are a number of works where it is indirectly present [27,28,29], however, these studies are clearly insufficient.

The problem of survivability and linear scale effect is especially urgent for multi-element steel structures. Steel is a good structural material; moreover, a great experience in designing and operating metal structures has been accumulated in engineering practice. But despite the development of the analytical apparatus, computer technologies and modeling methods, scientists and engineers face with the problems of designing, creating and operating complex large-sized and multi-element rod systems. Metal structures (in contrast to reinforced concrete and stone structures) have a relatively small reserve in the redistribution of efforts. For example, local damage (failure of one of the elements or one connection) sometimes can be the reason for the bearing capacity loss of the entire structure, and if the element is basic and bearing, then the entire object can be even destroyed [30].

3. Reasons for the operational operation capacity loss

Recently there has been a tendency towards the structural complication of buildings and structures in the construction industry. This is expressed in an increase of spans lengths, the height marks dimensions, structural elements number, in the use of new materials etc.

The accumulation of damage, appearance and development of defects reduces the structures bearing capacity, therefore, for large-size and multi-element systems the probability of bearing capacity loss and a service life reduction increase.

Rod metal structures take a special place among building structures. They are widely used in various industries (overpasses, mine headframes, galleries, towers, masts, bridges). These structures are affected by quasi-static, cyclic, dynamic and random loads. They are operated in corrosive environments and are affected by temperature differences [31, 32]. As mentioned above, the building regulations used in the design of buildings and structures do not give the calculation of structures with developing defects and do not allow to predict the behavior of an object in emergency situations, which can be caused by many technogenic and natural factors in a highly industrialized region.

Analysis of the catastrophic failure cases of large-sized metal structures at stresses significantly below the yield limit shows that calculation methods based on the continuum mechanics classical approaches are often insufficient [33].

In metal structures there are always defects of various origins: metallurgical, technological, operational defects, which, lead to the appearance of cracks and fragile destruction of the structure under certain conditions, [11,19,34]. The speed of initiation and propagation of cracks is determined by the features of the structure, structural parameters, loads nature, aggressiveness and temperature of the operating environment. Elements of systems in the supercritical area of operation consistently fail, redistributing the load to other elements, and thus generate negative influences internal to the system itself [35]. External and internal influences lead to further failure of the elements, and the system goes into an emergency state. How quickly the emergency state of the system occurs will also depend on the degree of its static indeterminacy.

Failure (destruction) of one or several elements of the system does not mean the termination of its functioning. Studying the structure behavior in case of failure of its constituent parts and identifying additional reserves, for example, due to alternative (spare) ways of redistributing external influences, is an important practical task.

Structural damages according to the nature of the impact on the bearing capacity can be divided into changing:

- geometric characteristics of intersections;
- nature of the stress-strain state of structural elements;
- a constructive scheme due to a connectivity disturbance between the elements.

Assembling defects or manufacture defects, corrosion, the use of metal with characteristics below design values, design mistakes, incomplete accounting possible loads and an insufficient system of structural connections can lead to the destruction of rod metal structures. Data processing on emergency destruction of metal structures is presented in Table 1.

Table 1

Operating conditions influence,%	60
Human factor influence,% .	19
Destruction of individual structural elements,%	10
Sudden impacts,%	8
The reason is undefined,% .	3

Regarding to metal structures, corrosion is one of the most significant factors causing destructions. Unlike the classical tasks, many constants characterizing the element properties in a neutral environment are functions if the element is operated in an aggressive environment. Moreover, the degree of their change is not the same for different points of the structure. Thus, an aggressive environment impact leads to the appearance of an induced (time-varying) inhomogeneity of geometric and, in some cases, structure mechanical [36, 37].

The safety problem solution of any design structure comes down to ensuring its main properties: reliability and durability. Conventionally, structure operation period before its destruction can be represented by three phases (Fig. 3):

the first - corresponds to the normal operation mode of the structure, it is the longest in time (0-t_1);

the second - corresponds to the limited operation capacity of the structure with accumulated defects, damages, failures of some elements, that is "survivability" (t_1-t_2);

the third - corresponds to the complete destruction of the structure, which occurs suddenly in a short period of time (t_2-t_3).

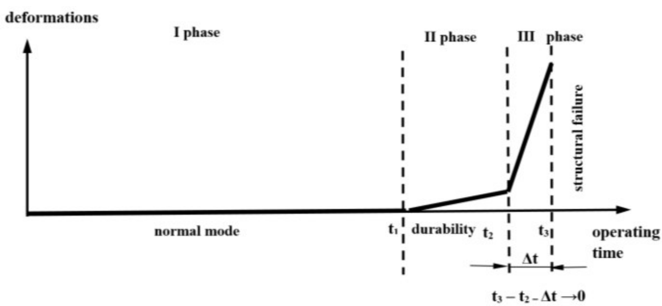

Fig. 3. The period of a structure operation

Often the assessment of the technical condition of long-term operating metal structures does not contain the main quantitative characteristic (the reliability of the structure). This is caused by the fact that, as a rule, in practice, there are no reliable and complete statistical data on the input and output parameters of the structure. Such limited information creates certain difficulties for forecasting the structure trouble-free operation. At the operational reliability assessment of a structure it is necessary to take into account the actual duration (section 0-t_2 in Fig. 3) of its operation, that means to identify the reserve (section t_1-t_2 in Fig. 3) of its bearing capacity [5,37].

4. Survivability (stability) of damaged structures

Within the framework of the developing theory of technical systems safety, the process of forming a system of quantitative indicators of survivability and safety is currently in process. The survivability quantitative characteristics of are the closest to engineering practice and can be most quickly introduced into design calculations. This requires clear qualitative definitions and quantification algorithms. In this regard, a number of survivability characteristics and methods for their assessment are proposed.

Let us consider the survivability indicators for the following structure operation mode outside the nominal operating conditions:

1 - emergency initiation mode. This is a short-term duration mode, when the design parameters of the structure go beyond the permissible values.

2 - emergency development mode. This is a free operation mode, when the structure degrades until it completely loses its strength, bearing capacity, and structural integrity.

The most common survivability indicators for these two modes belong to one of the following groups:

1 - system safety reserve;

2 - compensation characteristics;

3 - degradation intensity characteristics.

We will consider that a structure has a systemic safety reserve in the case when because of structural redundancy and increased classical safety reserves of individual elements the structure turns out to be weakly sensitive to the occurrence of local damages and destruction. In this case the damage occurrence and the loss of the individual elements' bearing capacity leads to a such redistribution of internal force factors that classical safety reserves in all the remaining structural elements are within acceptable limits and as a result the emergency situation does not arise. A quantitative assessment of the system safety reserve can be performed using finite element technologies in one of the following positions:

1 - the structural material depending on its properties and environmental factors can be destroyed mainly according to a fragile or viscous scenario;

2 - a structural material is considered as a continuous or stochastically defective medium.

Under the assumption of a predominantly fragile state of the material the task of assessing the system safety reserve is reduced to modeling the destruction of individual load-bearing elements of the system, which is ensured by removing them from the model. In this case, a search is performed for the most loaded element with the smallest reserve relative to the ultimate strength, which can be considered a system reserve.

Considering the predominantly viscous state of the material, a series of computational experiments is performed decreasing in the stiffness characteristics of the material in the forecasted destroyed structural elements. Then, force characteristics (reserve ratios related to the yield limit in overloaded elements) or geometric characteristics (the ratio between the area or volume of the entire structure to the area or volume of elements in a state of plastic flow) can be considered as a systeme strength reserve.

Taking into account a randomly distributed defectiveness is performed in the following way. If a priori information on the probabilistic characteristics of defectiveness is absent, a crack-like defect (the maximum permissible according to the current of **crack detection** standards) is introduced into the most loaded zones of the structure. If probability distribution of defectiveness parameters is known, randomly distributed defectiveness is generated in accordance with this distribution. In this case the systemic strength reserve is determined taking into account the stresses concentration in the defects area.

The compensatory survivability characteristics are proposed to understand as structure properties to resist the transfer from the initiation mode to the emergency development mode. In fact, they characterize the complex stability of the tress-strain state parameters. Their deviations appear in the conditions of the emergency initiation. Compensation characteristics are functions of the structure system properties. Compensation characteristics are provided by the flexibility of the structure and its elements, by redundancy, limits conditions.

The compensation characteristics can be characterized quantitatively in the following way. Firstly, temporary compensation characteristics are considered as period of time when adaptive effects appear in the structure and stress state parameters are stabilized. Secondly, force compensation characteristic can be determined as parameters of the wave processes of the spreading deformations and stresses in case of structure damage and compensation effects occurrence. Thirdly, energy compensation characteristics can be considered also. They are estimated as positive if the level of accumulated elastic energy decreases during the damage compensation, and as negative otherwise.

The degradation intensity characteristics as survivability indicators can be characterized as follows. In the emergency development mode the survivability indicators characterize both the bearing capacity fall speed and its time derivative, that means the conditions for the acceleration or deceleration of the ongoing degradation processes. In this case quantitative estimates are: crack growth speed and corrosion damage speed, changes of these speeds, the total length of the growing cracks system, indirect characteristics of the degradation processes intensity (acoustic emission intensity, local temperature increases in damage zones, etc.).

As for the special survivability indicators, they must be differentiated according to the types of structural forms and operating conditions.

The following types of structural forms are considered:

- rod three-dimensional structures;
- frame structures;
- three-dimensional plate structures;
- shell structures, including reinforced and multilayer ones;
- volumetric details and structures.

Design survivability calculations are closely related to a design case concept. The design cases choice plays a special role in the designing large three-dimensional structures. It is related to the fact that not taking into account different combinations of support conditions and loads can have catastrophic consequences, expressed in the sequential destruction of the total system. Thus, it is advisable to expand the design case concept. And in this case it is assumed to include in the design case not only the so-called emergency combinations of loads, but also to consider the destruction of one bearing element (one by one) as a probable situation. It makes it possible to analyze possible emergency scenarios at design calculation stage and exclude the "domino effect", which means uncontrolled catastrophic development destruction of the entire system.

Determining the parameters and ensuring the survivability (stability) of load-bearing structures require an complex formulation and research on various aspects of the design, construction, production, installation and operation of technical systems. Currently survivability field research is carried out in the following directions.

1. Substantiation and formulation of basic concepts, principles, qualitative and quantitative indicators of survivability and related categories regarding parts and elements of structures, joints, bearing structures and technical systems in general.

2. Analysis and change of load-bearing structures design calculations, development of computational algorithms for survivability indicators calculation, regulation of calculations and development of regulations documents drafts.

3. Studying survivability of typical structural forms of load-bearing structures, the development of increased survivability structural forms and developing the theory of such structural forms construction.

4. The comprehensive modeling of emergency situations of technical systems structures, including both the study of external causes and conditions of accidents and catastrophes and study of the internal force processes, deformation, energy, wave processes of structures.

5. Research of technological and operational defectiveness of technical systems, including probabilistic modeling of technological defectiveness processes, identification of random nature physical

regularities of scattering sizes and defects location, statistical analysis of non-destructive testing data.

6. Modeling the stress state in local zones of technological and operational defectiveness, including the development of computational technologies for modeling the damaged zones stress state and the creation of probabilistic stress state models in local zones of defectiveness.

7. Development of structural and force methods complex for survivability ensure, which implies the formulation of bearing structures shaping algorithms according to requirements of survivability, optimal structural elements design according to survivability criteria, resource management and survivability management models in the presence of local damage.

8. Development and design of a complex of technical devices, instruments, equipment which increase the operation safety of technical systems and their survivability in emergency situations.

5. Failure protecting methods of multi-element metal structures.

5.1. Reliability improvement techniques

All methods of increasing and maintaining reliability are divided into three large groups: design methods, manufacture methods and operation methods.

Design reliability improvement methods:

- reservation;
- system simplification;
- the most reliable elements selection;
- creation of schemes with limited consequences of element failures;
- facilitation of electrical, mechanical, thermal and other modes of elements operation;
- standardization and unification of elements and joints;
- built-in control;
- checking procedure automation.

The effectiveness of these methods lies in the fact that they allow to build reliable systems from unreliable elements. These methods can reduce the system failure rate, reduce the average recovery time and system constant work.

Manufacture reliability maintenance methods.

At manufacturing elements reliability can be increased by improving the production technology, by automating production processes, using statistical product quality control, training elements and systems. All these methods make it possible to reduce the failure rate of system elements.

Operation reliability maintenance methods

It is extremely difficult to improve the reliability of the system during its operation. It happens because the system reliability is created mainly at its design step, is ensured during manufacture, and it is only consumed during operation. Its consumption speed depends primarily on the operation methods and conditions.

The task of ensuring the safe structures operation is both to increase the system reliability and to save this reliability for as long as possible in the process of its design and manufacture.

Scientific operation methods include scientifically based methods of carrying out preventive measures and repairs: frequency and depth of checks, time regulation of the continuous system operation etc.

It should be noted, however, that reliability is not only consumed during the operation. At correct operation it is also possible to increase the reliability of systems. Indeed, if preventive measures prevent failures, then this is analogous to reducing the system failures rate. The only difference is that at this stage the reliability of the elements does not actually increase, as it can be realized in design and manufacture, but timely renovation or repair of elements realize. These elements are not yet failed, but their failure probability has greatly increased.

Operation has a very strong influence on the design and manufacture of a newly developed system. It happens because data regarding failures of elements and systems obtained during its operation fully characterize its reliability and therefore are often used as the initial data for the designing highly reliable systems.

Collection, scientific processing and generalization of statistical data concerning the systems elements failures is one of the important functions of technical operation.

5.2. Comparison of different methods of reliability improvement

The effectiveness of a particular method can be assessed by comparing the quantitative characteristics of the reliability of systems which are identical in design and principle of operation, but different in methods of increasing reliability.

It is convenient to take the reliability gain as an efficiency criterion for all or most of the quantitative reliability indicators. Evaluation based on the most important indicators is necessary because the effectiveness of a method significantly depends on the criterion that is chosen to assess the reliability. Analysis results are often contradictory. For example, if reliability is estimated by the average time of zero failures work, then the most effective way is reducing system failures rate. But if we estimate the probability of zero failures work, the best option will be to choose the redundancy. At assessing the system reliability by the availability ratio, it may happen that the best way is to reduce the average recovery time.

It is possible to rationally choose one or another method of reliability increase only when the system operating conditions and the methods effectiveness are known.

Conclusions

The analysis of publications shows that currently a sufficiently coordinated interpretation of the construction objects properties which characterize their operational capability has not yet been achieved.

Some scientists base on the analysis of the sources of operational capability fails, others analyze their consequences. It is explained by fact that the theory of the systems survivability of is at the stage of formation and formalization into an independent scientific discipline.

It is necessary to distinguish between general survivability indicators, which are universal for all types of bearing structures, and specific ones, which differ from each other for various types of structural forms. These characteristics follow from the consideration the structure as a unit, as a system of interacting elements. Thus, in this case the structure of the system is one of the most important factors in its survivability formation, which is not limited by a set of individual elements' characteristics.

Operating experience should always be used in the design and manufacture of reliable systems, and the results of design and manufacture should always be used to improve operating methods.

Reliability improvement methods allow to design the highly reliable systems. The choice of method is determined by the properties of the designed system. Very often it is not possible to design a highly reliable system using only one method of increasing reliability. It is needed to use all the methods or most of the methods discussed.

The above methods of reliability increase are not required for any system. Some methods can be used to improve the reliability of one class system, other methods for another. It all depends on the system type and its operation conditions.

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