International Journal of Advanced and Applied Sciences, 8(12) 2021, Pages: 25-35

Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Analysis of changes in the survivability of building structures reinforced after an emergency dynamic impact in the context of assessing the security of buildings in the oil and gas industry

Dmitry Yu. Sarkisov [1], Vladimir V. Krylov [2,*], Emirlan T. Ergeshov [3], Jawdat S. Goussous [4]

[1]*Department of Reinforced Concrete and Stone Structures, Tomsk State University of Architecture and Building, Tomsk, Russia*
[2]*National Research Moscow State University of Civil Engineering, Moscow, Russia*
[3]*Faculty of Civil Engineering, Tomsk State University of Architecture and Building, Tomsk, Russia*
[4]*Department of Architecture Engineering, School of Engineering, The University of Jordan, Amman, Jordan*

ARTICLE INFO

Article history:
Received 24 June 2021
Received in revised form
7 September 2021
Accepted 23 September 2021

Keywords:
Reliability
Survivability
Level of survivability
Elastic strain energy
Impact
Short-term dynamic load
Reinforced concrete

ABSTRACT

The relevance of the subject matter is conditioned by the technical complexity of the oil and gas facilities due to the increase in the volume and rate of raw materials production, which may be affected by shock-wave loads in emergency situations. The causes of the impact can be explosions, heavy cargo falls, terrorist attacks, natural and anthropogenic disasters, etc. These situations are very likely to cause significant damage to the building structures of industrial facilities, which necessitates their reinforcement. For further safe operation of the facility, reinforced structures must have survivability under repeated impacts no less than before the reinforcement. Given the fact that the survivability of buildings is a complex characteristic influenced by many factors, and it itself is a component of the security of a hazardous production facility, research in this area is topical. The purpose of the study is to test the developed method for assessing the survivability of a building structure under short-term shock-wave load based on the energy parameter and to analyze the results obtained in the context of assessing the security of critical oil and gas facilities. Research methods: Measurement of accelerations, deflections, and loads by strain measurement methods, graphoanalytical method of study using the Microsoft Excel software. A method for assessing the level of survivability of a building structure under shock-wave loading for critical oil and gas facilities using the survivability coefficient is developed. Using specific tests of conventional and cage-reinforced bending concrete elements for short-term dynamic load, the values of the specified coefficient are obtained. The values are compared and conclusions are drawn.

1. Introduction

The oil and gas industry is currently one of the key elements of the Russian economy. Many construction facilities of the oil and gas industry belong to the category of hazardous production facilities (HPF), and some to the category of critical infrastructure (CI), with a high risk of emergency situations caused by explosions or other short-term dynamic impacts. When the critical infrastructure is destroyed, there is significant direct damage caused by the cost of the facility itself, as well as indirect damage associated with the lack of supply of the population and economic facilities with the necessary energy resources. The main indicator for such facilities is security, which is determined by the ability to withstand the occurrence and development of adversities in standard and non-standard operating conditions (Makhutov et al., 2017; Bondarenko et al., 2020).

There are two main principles ensuring the security of the critical infrastructure:

- Creation of systems that are practically guaranteed to be protected from the occurrence of critical local damage during the specified service life.
- Creation of systems that are able to operate in the presence of local damage (it is assumed that the survivability of the system, that is, after the occurrence of local damage, there must be a time

* Corresponding Author.
Email Address: krylov5901@ust-hk.com.cn (V. V. Krylov)
https://doi.org/10.21833/ijaas.2021.12.004
Corresponding author's ORCID profile:
https://orcid.org/0000-0003-1032-5098

reserve necessary to eliminate the damage). Notably, the first principle is much more expensive and can be applied rather only for individual strategically important facilities (SIF). The high level of uncertainty in the intensity of loads and impacts in standard and non-standard situations, when determining the stress-strain behavior of materials, is compensated for by a significant overestimation of all the necessary parameters. With regard to building structures, this can manifest itself in a significant increase in sections, reinforcement congestion, the use of high-strength expensive materials, etc. The second principle is more economical in the long term, but it involves conducting a number of studies and analyzing a large number of characteristics of the facility, which include the degree of their change and dependence on each other during operation and at the stages of supercritical operation. In this study, research was carried out within the framework of the implementation of the second principle. The security of the critical infrastructure (CI) is expressed by the functional set of basic parameters, for example (Makhutov, 2018; Melnyk, 2020):

$$Z_k(t) = F_z\{R(t);\ S(t);\ L_{ld}(t); P_{PR}(t); R_{Nt}(t); R_\sigma(t)\} \quad (1)$$

where: $Z_k(t)$ is security level of the facility; $R(t)$ is risks; $S(t)$ is safety; $L_{ld}(t)$ is survivability; $P_{PR}(t)$ is stability; $R_{Nt}(t)$ is rigidity; $R_\sigma(t)$ is strength. The security level of the CI facility should be laid down at the project stage, and then, with some permissible deviations, established at the construction stage and maintained during the operation of the facility in both regular and emergency situations. The analysis of the security of facilities is inextricably linked with the assessment of the risks of adverse processes and events and their associated damage. The risks are determined based on the generalized functionality:

$$\mathrm{R} = \sum_{i=1}^{n}(P_i; U_i), \quad (2)$$

where: R is risk; P_i is a probability of occurrence of an event; U_i is the mathematical expectation of damage. When implementing algorithms for reducing risks to acceptable ones, particular importance is attached to the mechanics of deformable medium, that is, the choice of parameters for determining and regulating the strength, average life, reliability, survivability, and security for all stages of the life cycle of facilities. A change in certain parameters in the system under consideration inevitably leads to a change in the damage when an adverse event occurs. That is, when any parameters change, the entire system changes, and these changes must be analyzed in terms of increasing or decreasing the level of security of the critical infrastructure facilities. Thus, according to the established conventional approaches to the structural design, the perception of emergency dynamic impacts is mainly subject to requirements only for load-bearing capacity. But the norms for deformations, deflections, and cracking are not provided. It is likely that after an impact, the construction structure would receive various types of damage, but not collapse (Popov and Rastorguev, 1980; Galyautdinov, 2018).

Subsequently, it would be necessary to perform work to restore operational suitability. Based on the fact that it is quite difficult to interrupt or stop the technological processes taking place in such buildings, and it is also not economically feasible, then most likely the option associated with reinforcing the damaged building structure will be chosen, rather than its replacement. Reinforcement is local work, which in most cases does not require the dismantling of a part of the coating or other structures. In the construction of such buildings and structures for load-bearing frames, precast or cast reinforced concrete is often used, therefore, this study considers reinforced concrete structures. One of the most common options for strengthening concrete structures is the reinforced concrete collar, carried out by joint grouting of damaged structures with concrete and the installation of an additional reinforcement frame. It is known that in reinforced concrete, due to its nonlinear properties under short-term dynamic loads, complex processes occur (Plevkov, 1996; Baumung et al., 2001; Plevkov et al., 2004; 2008; 2013; Sarkisov et al., 2020; Venkiteela et al., 2013; Belov et al., 2016; Dong et al., 2017; Odnokopylov and Sarkisov, 2017; Gao et al., 2017; Chen et al., 2017; Demyanov and Kolchunov, 2017; Savinykh et al., 2018; He et al., 2020; Likhov et al., 2020; Orton et al., 2021). Therefore, the design of reinforced concrete structures under such types of impact is a scientific problem. However, taking into account that it is necessary to model an already damaged structure, and even reinforce with a concrete collar, the task becomes much more difficult. In fact, in the absence of a developed theory, the solution of such a problem requires a separate theoretical and experimental study, the findings of which will be suitable only for a specific facility. In the framework of the current production process, taking into account the required time and cost of work, such studies are not always feasible. Therefore, during design, often only a rough estimate of the load-bearing capacity of the structure with the reinforcement is calculated, while other parameters are not calculated. As a result, a design decision is often implemented with a large margin of safety. An example of constructive, rather than calculated solutions here can be, for example, the minimum thickness of the collar based on the need to place a reinforcement frame in it and observe the necessary protective layer, or the use of concrete for the collar of no less strength class than that of the structure itself (Markush et al., 2018).

However, it is essential to remember that the main goal for ensuring further safe long-term operation is not only to restore the strength of the building structure but also to provide the necessary level of security in the event of possible repeated exposure. This study pays much attention to the survivability of the system, which is considered in the aspect of the security functions of the critical infrastructure of the oil and gas industry. The concept of survivability of a building as a whole as a complex technical system is broader than its constituent elements. For buildings and structures, many parameters must be assessed, such as strength, stiffness, deformability, crack resistance, etc. The combination of various indicators would give an idea of the survivability of the system under consideration. Thus, there may be situations when an overestimation of one technical parameter causes a change (decrease or increase) in another, which together can lead to a decrease in the survivability of the structure as a whole. Using the theory of survivability for technical systems (Odnokopylov and Bragin, 2014; 2015a; 2015b; Odnokopylov and Rozayev, 2014; 2015; 2016), it is possible to more accurately estimate the residual resource of building structures or facilities as a whole after exposure to excess short-term dynamic loads. Since the behavior of a building structure during operation is described by random factors, the solution of such problems must be performed using probabilistic methods, which are quite labor-intensive, both methodologically and mathematically (Li and Di, 2011).

As a result, the above situation with the strengthening of the load-bearing structures of critical infrastructure of the oil and gas complex requires either a complex control of all parameters (using probabilistic methods) or the implementation of such a solution, in which the original initial parameters of the structure are likely to be restored. That is, it is necessary to implement reinforcement in such a way that the strength, rigidity, and deformability of the structure would be close to the indicators before the dynamic load impact. Such a solution would allow preserving the overall survivability of a structure laid down in the project without spending a lot of time and money on the revaluation of all the parameters. As a result, a not very time-consuming method for assessing the degree of survivability of a building structure should be developed, which would take into account not only the strength parameters but also the deformative ones. The authors of the study have previously developed a method for assessing the degree of survivability of a building structure (Odnokopylov et al., 2018; Odnokopylov et al., 2019) based on the application of the survivability factor. The aim of the studies was to estimate the energy parameter during the movement of the structure during its deformation, that is, both the effective load and the deformation of the structure were investigated. The purpose of this study is to test the developed method for assessing the degree of survivability of a building structure under short-term shock-wave load based on the energy parameter and to analyze the results obtained in the aspect of assessing the security of critical oil and gas facilities.

2. Materials and methods

The task was to test the reinforced bending concrete element for a short-term dynamic load, then to strengthen the damaged element with the reinforced concrete collar and re-test it for the same load. In this case, the parameters of the case were taken without calculations for general design reasons, that is, the thickness was taken based on the possibility of placing longitudinal reinforcement of the same diameter as the original sample, the class of reinforcement and concrete were also taken as in the original sample.

The prototype was a reinforced concrete element with a length of 2.0 m, with a cross-section size of 90*180 mm. The reinforcement was carried out by a spatial knitted frame with four principal reinforcing bars 10 mm diameter and A400 class, the lateral reinforcement was carried out by a 3 mm diameter reinforcing bars of B500 class, with a step of 100 mm in the support zone and a step of 150 mm in the span.

The concrete class was B25. The sample, reinforced with a concrete collar, represented a reinforced concrete element with a length of 2.0 m, with a cross-section size of 240*150mm. The thickness of the collar was 30mm. Cage reinforcement was made of 4 rods with a diameter of 10 mm of A400 class, the lateral reinforcement was carried out with a bar of 3 mm diameter of B500 class, with a step of 100mm along the entire length. Cage concrete class was B25. The designs of both elements are shown in Fig. 1.

The conditions for fixing both elements were the same, in particular, hinged, the scheme was single-span, the calculated span was 1.8m. Studies of the operation of both elements were carried out on the effect of short-term dynamic load based on the pendulum impact test. In both cases, the sample was deformed by transferring the energy of a 430kg load falling from a height of 0.5 m. The model and construction of the stand are shown in Fig. 2.

During both tests, the following parameters were recorded: the effective load (in the middle of the span), accelerations, and deflections (five evenly distributed points along the length). To control the load value during the experiment, a weighing device of the strain-resistive type DST4126 was used. The sensor for measuring the impact from the falling load was installed in the middle of the span of the distribution beam. To increase the time of the load on the sensor, a set of rubber gaskets was installed on top. Accelerometers ARF-10000A and deflection meters WayCon RL150-G-SR were installed to record accelerations and deflections.

The sensor readings were recorded by certified measuring systems MIC-300m and MIC-036r. All sensors were connected via cables that were protected from interference, which achieved the necessary accuracy when synchronizing the readings in time. The assembled representation of the devices and sensors is shown in Fig. 3.

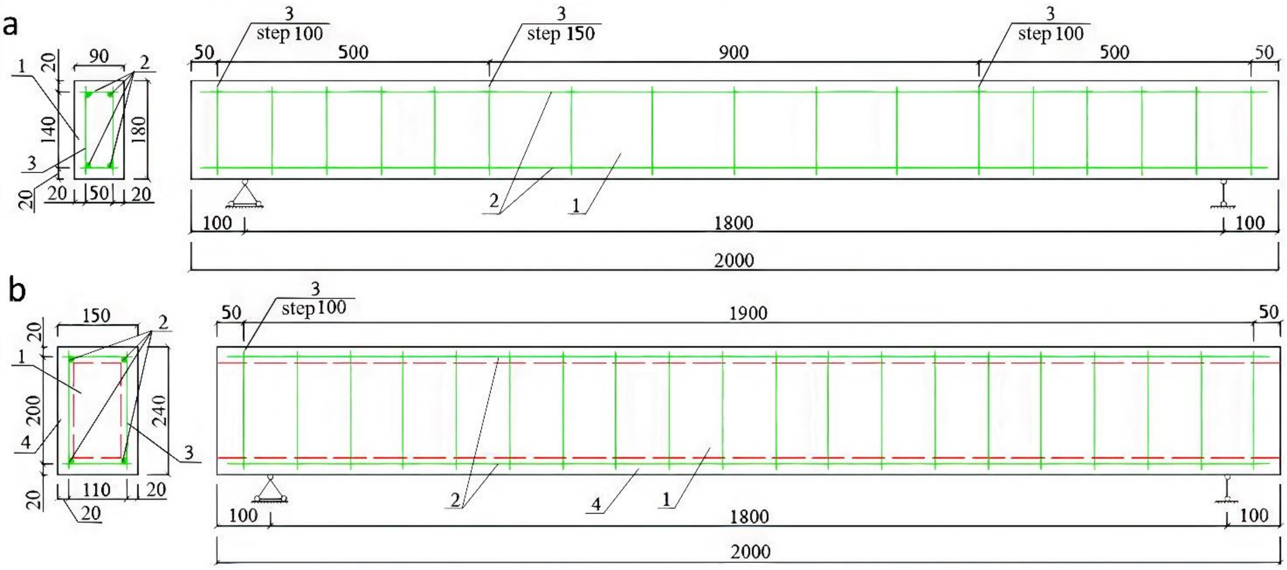

Fig. 1: Construction: a) conventional bending element; b) cage-reinforced bending element; 1–Concrete B25; 2–Longitudinal reinforcement Ø10 A400; 3–Lateral reinforcement Ø3 B500; 4–Concrete reinforcement B25

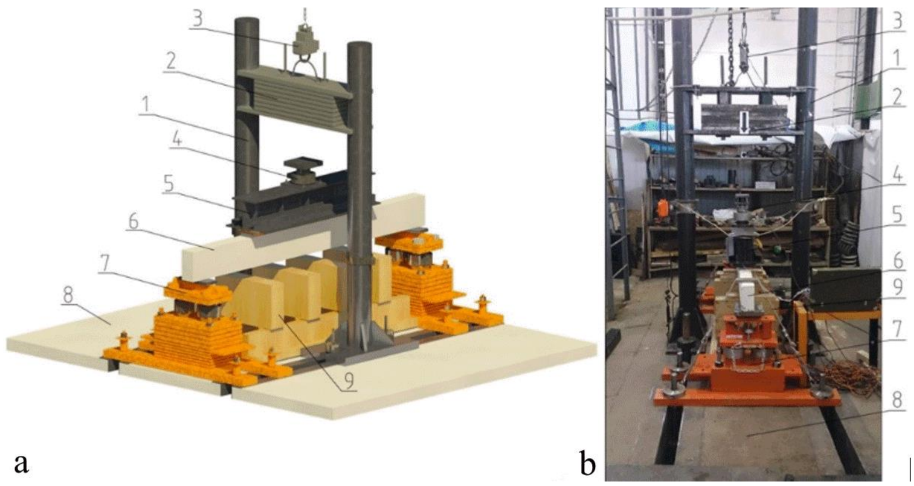

Fig. 2: General view of the test stand: a) model; b) construction; 1–Impact drop machine; 2–cargo weighing 430 kg; 3–release mechanism; 4–weighing device; 5–distribution beam; 6–experimental sample; 7–support; 8–reinforced floor; 9–safety device

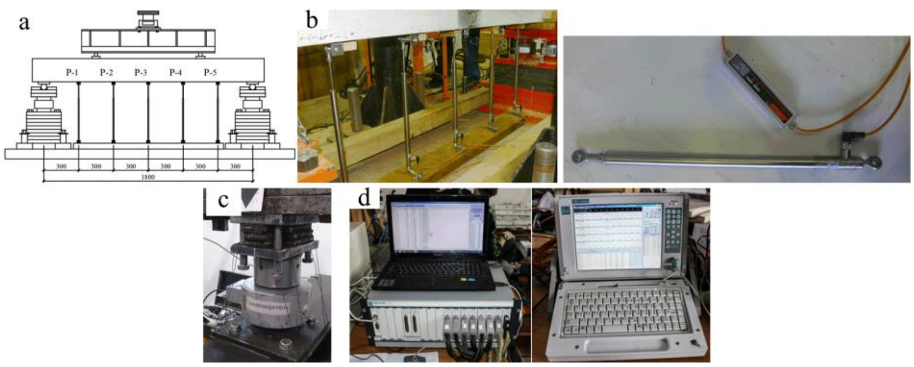

Fig. 3: a) WayCon RL150-G-SR deflection meters; b) ARF-10000A accelerometers; c) DST4126 weighing device; d) measuring systems MIC-036r and MIC-300m

3. Results and discussion

The registered source signals from all sensors were converted to the .xls format (Microsoft Excel) and the results were processed. After processing the obtained experimental data, graphs of the dependence of the force, deflections, and accelerations on time were obtained for both experimental samples. For the convenience of visual perception and analysis of the obtained data, the dependences for both samples were presented on the same graph and synchronized in time in the same coordinate axes. Since it was necessary to assess the operation, that is, to find the action of the forces on the given displacements, all the graphs were constructed for the sample points at the place of application of the forces. According to the method and arrangement scheme of the devices presented in (Odnokopylov et al., 2018; Davydchuk and Dema, 2020), the load application points (the support points of the distribution beam) were located in the quarters of the sample span. There were two supports, respectively, it was assumed that the load between the two supports was distributed evenly. The graph of the dependence of half of the effective force on time (in places of load application) is shown in Fig. 4.

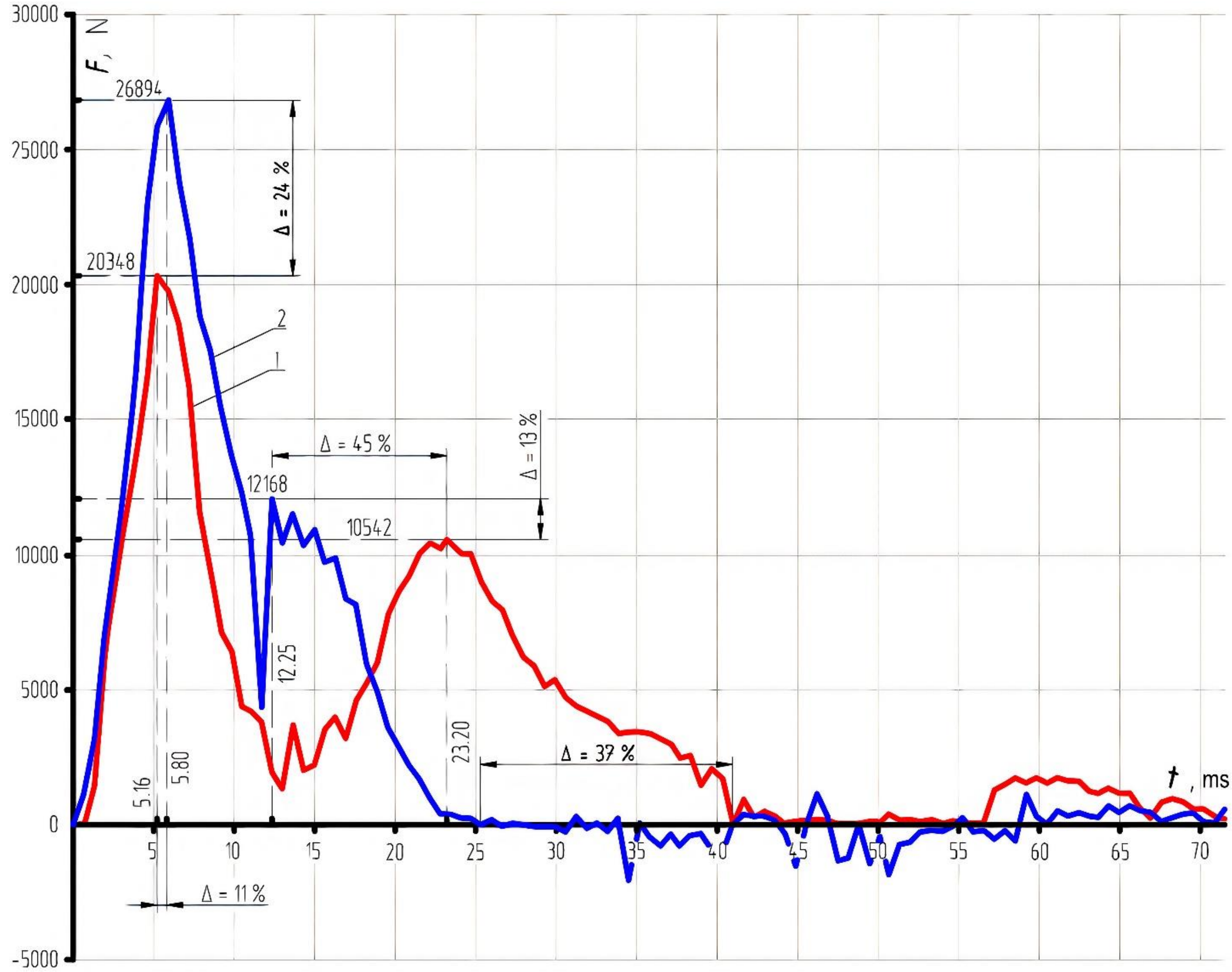

Fig. 4: Graph of the change in half of the effective force overtime: 1–for a conventional bending element; 2–for a cage-reinforced bending element

The analysis of the given dependencies for the conventional and reinforced concrete collar elements showed the following:

- The maximum load perceived by the reinforced element increased by 24% compared to the conventional one;
- The value of the second peak in the graphs differs by 13% (for the reinforced element, it was 12168 N, for the conventional element, it was 10542 N);
- Reaching the maximum load (the first peak) in time did not differ significantly for both samples (the deviation was 11%), but for the second peak, the time deviation was already 45%;
- Comparing the entire main time interval of the load impact, it was about 41 ms for the conventional element and about 26 ms for the reinforced element (the deviation was 37%). Thus, it was established that at the same loading parameters, the reinforced element perceives more load, at the same time, the process occurs more quickly. Representing both elements on the scale of destruction from brittle to viscous, the reinforced element, according to the presented dependencies, will be located closer to the brittle destruction relative to the conventional one. Further, the obtained dependences of the deflections of both elements on time were analyzed (Fig. 5).

The following was established:

- The maximum deflection value for a conventional element was about 24mm, and for a reinforced element r 8mm, the deviation in values was 62%;
- The time to reach the maximum deflection for a conventional element was about 30ms, and for a reinforced element it was about 10ms (deviation was 66%);
- On the graph, for a conventional element, the peak is blunter and more stretched over time, and for a reinforced element, it is sharper.

Thus, a conventional element is more energy-intensive than a reinforced one, the process of its deformation is more stretched over time.

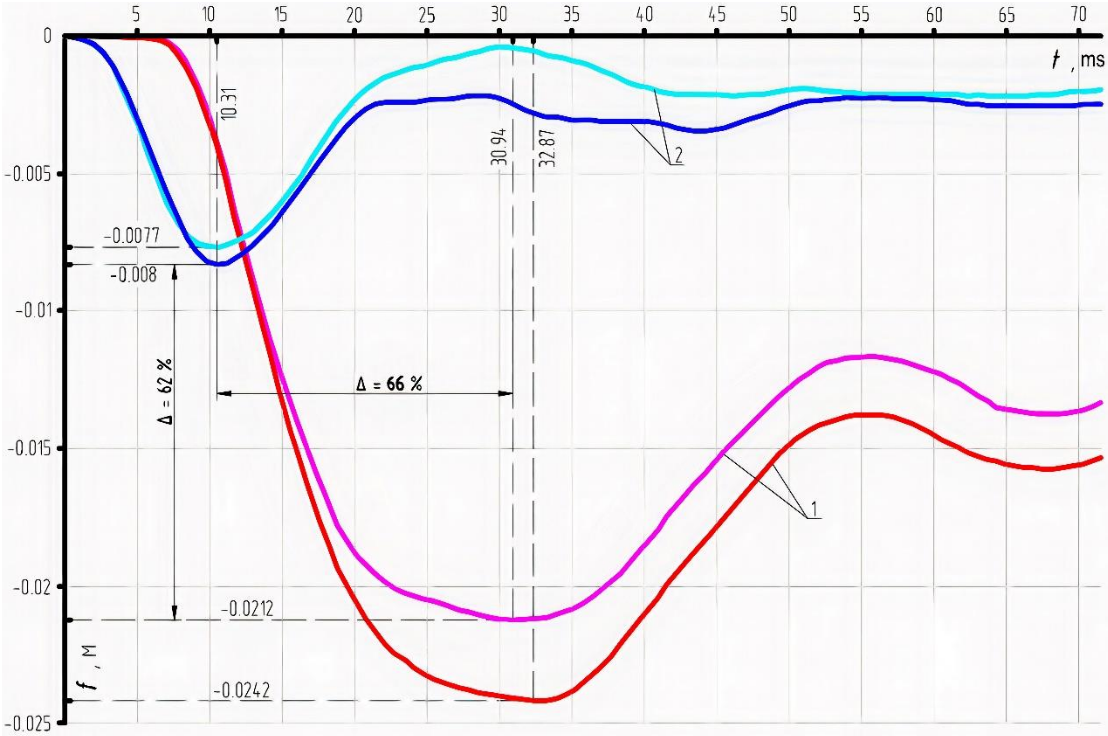

Fig. 5: Graph of changes in the deflections of the sample at the places of application of the load over time: 1–Left and right for a conventional bending element; 2–Left and right for a cage-reinforced bending element

Notably, the viscous fracture is more energy-intensive compared to brittle, that is, a conventional element is less prone to brittle fracture than a reinforced one.

As a result of the analysis of the obtained acceleration graphs (Fig. 6) for the conventional and reinforced element, the following is noted:

- Higher acceleration values were registered for the reinforced element, compared to the usual deviation for the first peaks which was 37%, the deviation for the second peaks was 70%;
- In the case of the reinforced element, a faster process was observed, with peak time delays of 58% and 44% for the conventional sample compared to the reinforced one.

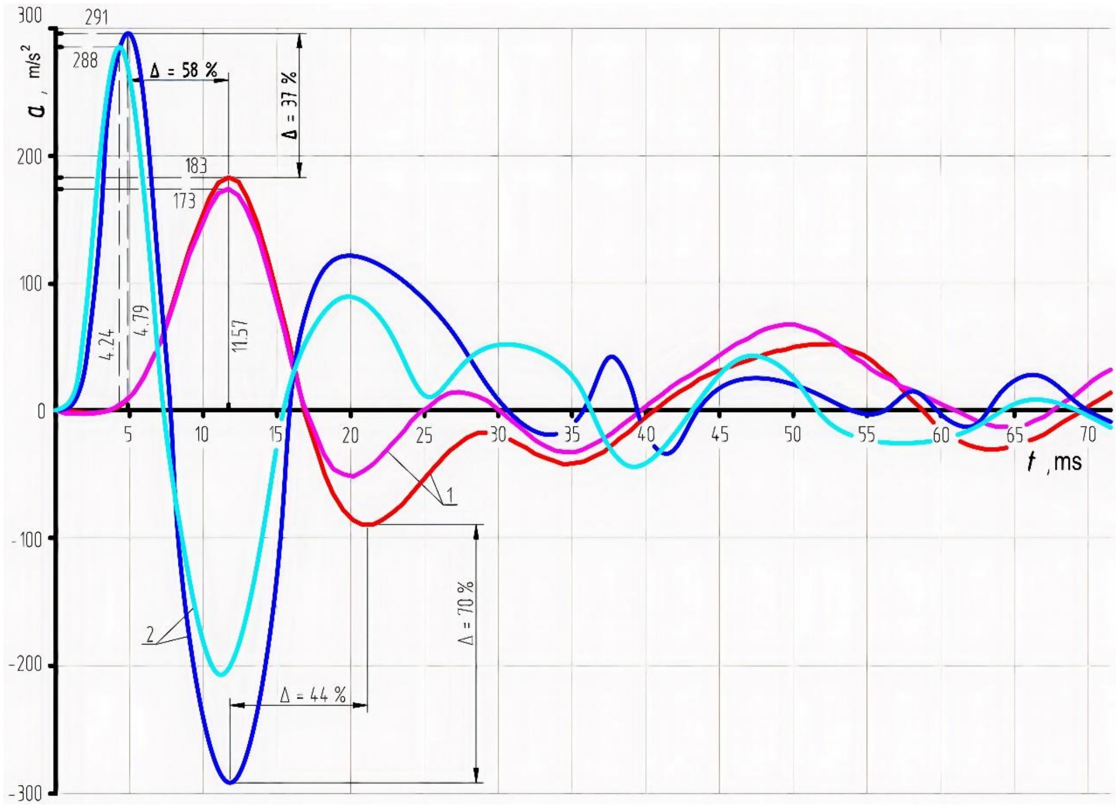

Fig. 6: Graph of changes in the accelerations of the sample at the places of application of the load over time: 1–Left and right for a conventional bending element; 2–Left and right for a cage-reinforced bending element

The graphs show that the reinforced structure has become more rigid compared to the conventional ones, the amplitudes of its oscillations have decreased, the frequency has increased, and the periods have also decreased. This behavior of the structure leads to a reduction in the time period during destruction. For both experimental samples, a graph of the forces at the given displacements was plotted (Fig. 7). Due to the fact that the load was transmitted to the samples through a distribution traverse at two points, the Clayperon theorem was used to find the impact (when the engineering structure is affected by a group of external forces, the impact of these forces is equal to half the sum of the products of each force by the amount of the corresponding displacement caused by the entire group of forces).

The analysis of the graphs showed:

- The maximum peak on the work schedule for a conventional element exceeds the peak for a cage-reinforced element by 24%;
- The time lag of the maximum peak of operation for a conventional element relative to a reinforced one is 52%. From the graphs, it can be seen that when deforming a conventional element, more work is done relative to the deformation of the reinforced one. It is known that an increase in the amount of work is characteristic of material with a bigger resource of plastic deformation. And plastic deformations are more characteristic of a viscous fracture than of a brittle one.

Crack patterns were also obtained for both tested elements (Fig. 8), and the following was found:

- in a conventional element, a greater number of cracks was formed than in a reinforced element;
- the crack opening width was also larger for a conventional element.

The viscous cracks have a larger opening angle (they are more obtuse), while brittle cracks have a small opening angle. From the obtained diagrams, it can also be seen that the nature of crack development in the reinforced element is more biased towards the brittle behavior of the structure relative to the conventional element.

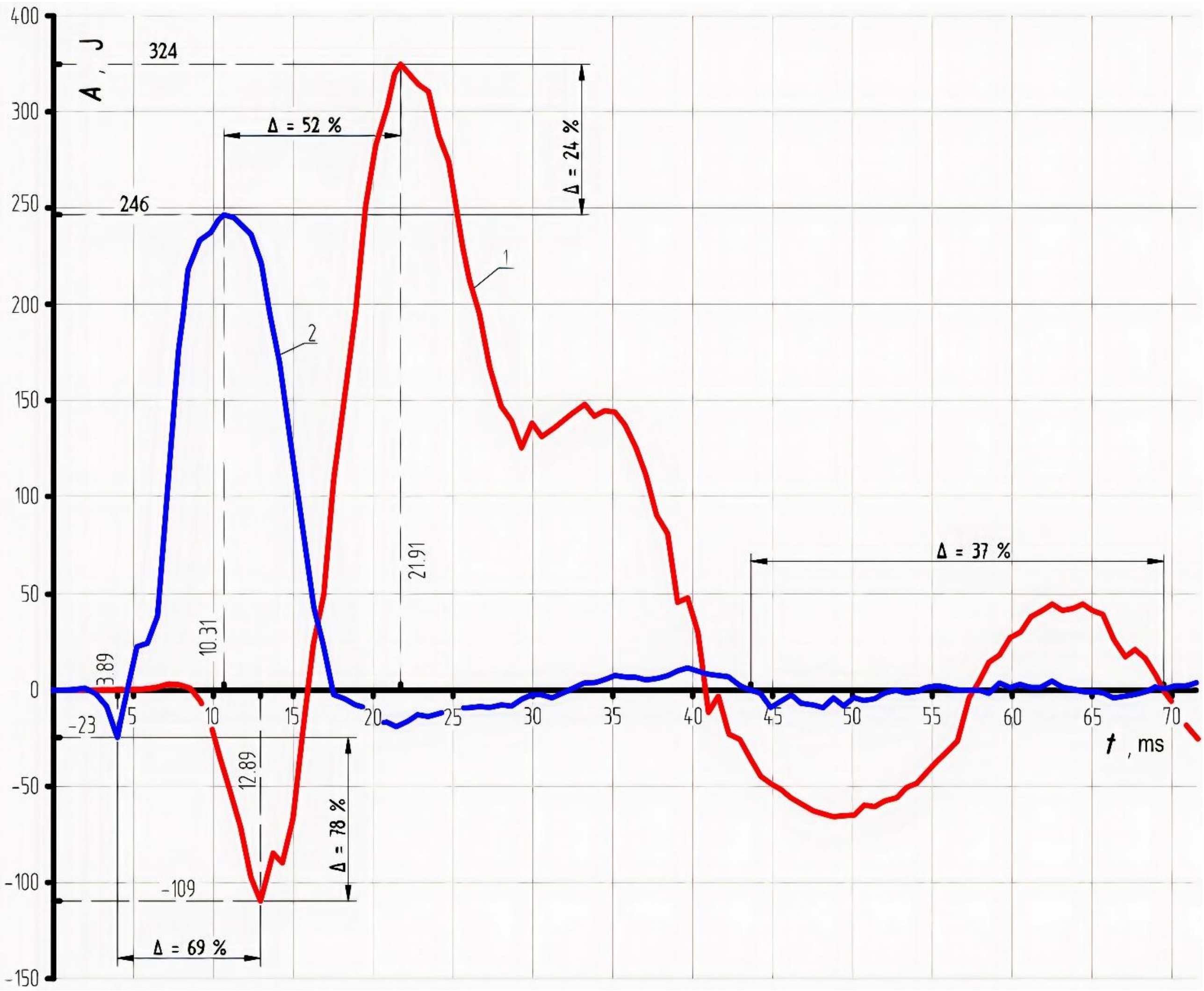

Fig. 7: Schedule of operation changes: 1 – for a conventional bending element; 2 – for a cage-reinforced bending element

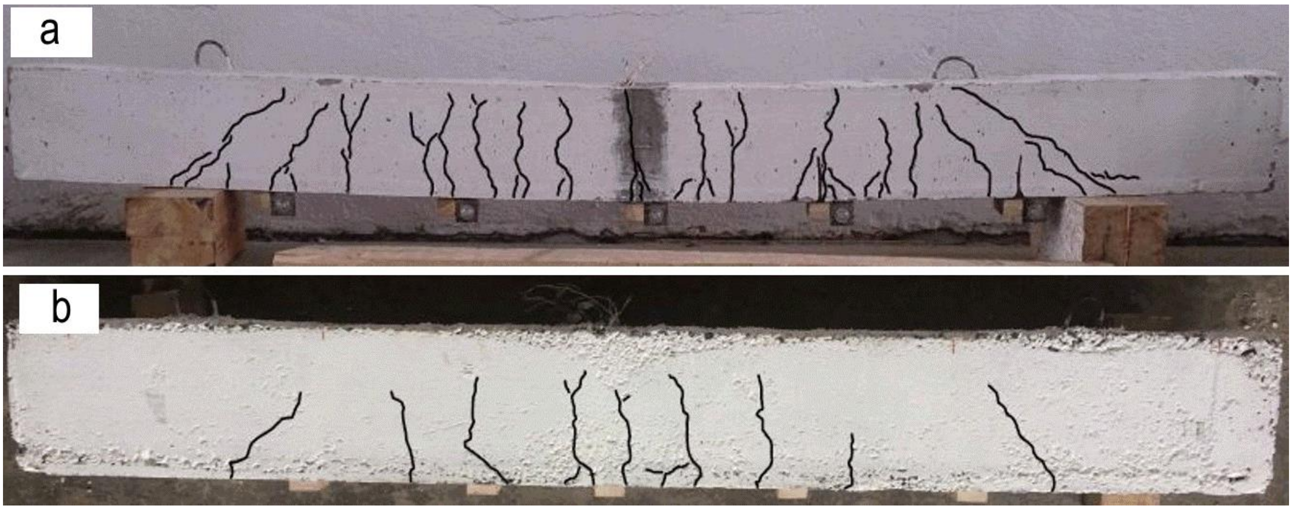

Fig. 8: The scheme of crack propagation: a) the conventional bending element; b) the cage-reinforced bending element

As a result of the analysis of all the data presented, it can be seen that the behavior of a bending element reinforced with a concrete collar is more brittle than the behavior of a conventional element without reinforcement. In turn, the more fragile behavior of a reinforced structure in a real structure will reduce its survivability relative to the survivability of the structure before reinforcement. Accordingly, it is necessary to assess the survivability of building structures and facilities in general when performing any reinforcement work. To assess the survivability of real production facilities, express methods should be used, which allow relatively quickly assessing the change in this parameter.

Admittedly, in the case of elastic deformation after removing the load, due to internal energy, the elastic forces perform bending of the sample. Estimating the difference between the energy for the time period that characterizes the movement of the sample down (to the maximum deflection), and the energy of elastic deformation, due to which the sample moves up (the time period from the maximum deflection to the maximum bending), based on the law of energy conservation, the following can be calculated: the total amount of energy spent on destruction (plastic deformation); oscillatory movement of colliding bodies; energy transferred to the release of heat, etc. It is very difficult to take into account and accurately decompose the energy into all the indicated components under short-term dynamic action. Therefore, in the framework of assessing the survivability of building structures, the study suggests a survivability factor, which expresses the ratio of the total transmitted energy to the energy of elastic deformation of a solid body at one complete oscillation (deflection and bending). The value of the survivability factor can be calculated from the analytical dependence Eq. 3 given below:

$$k_{s.f.} = \frac{\int_b^d |A(t)|dt}{\int_0^b |A(t)|/dt}, \quad (3)$$

where: $k_{s.f.}$ is the coefficient of the survivability factor of the sample; A is the impact of forces at given displacements at each time (J); d is the time of maximum deflection (s); b is the time of maximum (stabilized) bending (s). Graphically, this is expressed in finding the ratio of the areas under the graph of the dependence of impact on the time for the necessary periods (the period from deflection to bending and the period from the beginning of deformation to deflection). In graphical form, the determination of the survivability factor for the tested experimental samples is presented in Fig. 9.

Here, for the convenience of displaying information, the values are translated into relative units by dividing by the maximum value (A_{max}) the maximum value of the impact of forces at given displacements for the entire time period of calculations (J). In Fig. 9, the area S_1 (shaded in red) corresponds to the total relative energy, and the area S_2 (shaded in green) corresponds to the relative energy of the elastic deformation of the sample. To obtain the absolute energy values from the graph, it is necessary to multiply the corresponding areas by the value A_{max}. As a result of the calculations performed, the values of the coefficients of the survivability factor were obtained.

For a conventional reinforced concrete element tested for short-term dynamic load, the value of the survivability factor was $k_{s.f.} = 0.246$. For an element reinforced with a concrete collar, tested for the same short-term dynamic load, the value of the survivability factor was $k_{s.f.} = 0.107$. Despite the increase in the load-bearing capacity of the reinforced element in relation to the conventional one by 24%, its survivability factor decreased by 56%. A decrease in the value of the specified coefficient for a structure reinforced after an emergency impact means a decrease in its survivability and the structure as a whole in comparison with the state before reinforcing, which can lead to adverse consequences and an increase in the risk of destruction of the structure during repeated exposure.

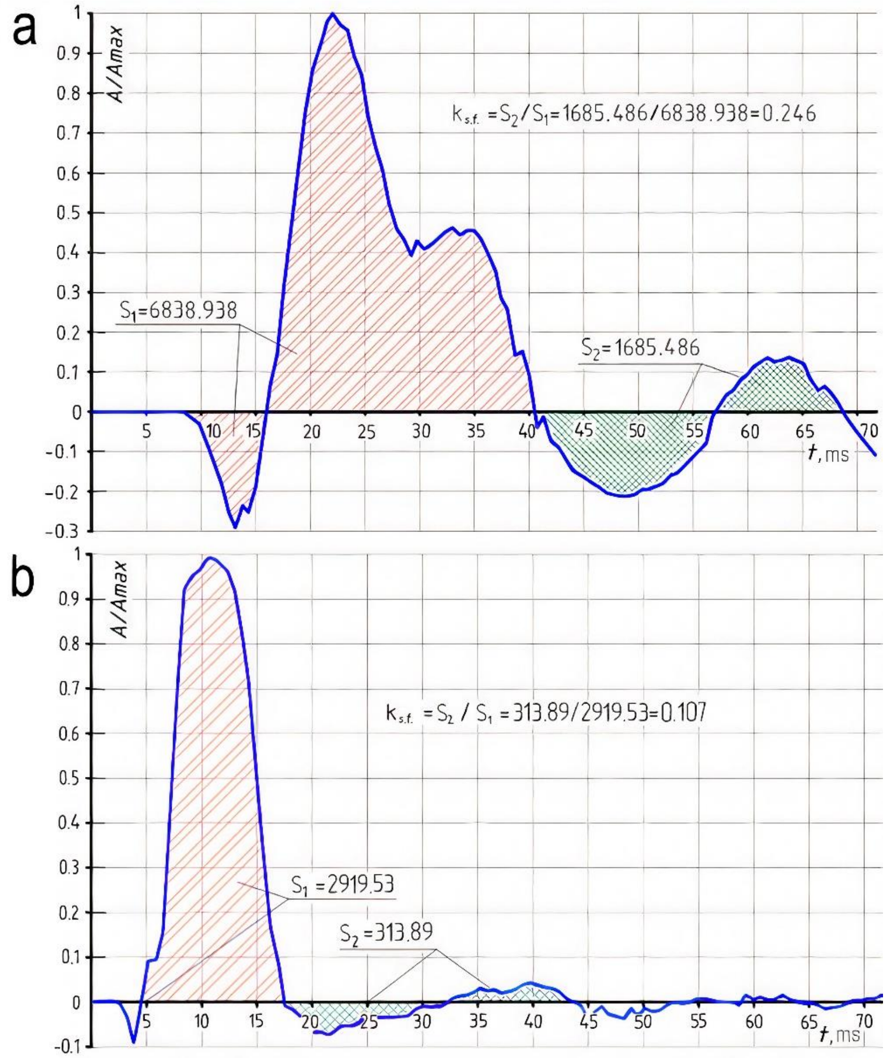

Fig. 9: Graph for finding the survivability factor: a) for a conventional bending element; b) for a cage-reinforced bending element

A comprehensive assessment of the condition of critical infrastructures of the oil and gas industry can lead to a decrease in its security. Therefore, to bring the structure into a state corresponding to the original one (before the impact), it is necessary to select such parameters of the reinforced concrete collar that, with a short-term dynamic impact, would provide similar survivability coefficients for the structure before and after its reinforcement, which together should not change the existing degree of protection of a critical infrastructure facility. The developed methodology and the survivability factor can also be useful, for example, in the design and assessment of the effectiveness of protective systems on pliable supports and systems that dampen vibrations to mitigate the dynamic impact on reinforced concrete structures under seismic, emergency shock, or explosive loads (Kumpyak et al., 2016; Chiaia et al., 2015; Mescheulov et al., 2017; Galyautdinov, 2017; Kumpyak and Mescheulov, 2017).

4. Conclusion

The previously proposed method for assessing the survivability factor of critical infrastructure facilities under shock-wave load, using the survivability factor based on the energy parameter, was tested on conventional and reinforced bendable concrete elements. On the examples of specific tests for short-term dynamic load, the value of the survivability factor was obtained for a conventional element which was $k_{s.f.} = 0.246$, and for a cage-reinforced element it was $k_{s.f.} = 0.107$. It was found that in a particular case, despite the increase in the load-bearing capacity of the reinforced element in relation to the conventional one by 24%, its factor of survivability has decreased by 56%. This study shows that a change in any parameter during the reinforcement of a building structure affects its other characteristics, which in general can lead to a decrease in the security of critical infrastructure of oil and gas facilities.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Baumung K, Bluhm H, Kanel GI, Muller G, Razorenov SV, Singer J, and Utkin AV (2001). Tensile strength of five metals and alloys in the nanosecond load duration range at normal and elevated temperatures. International Journal of Impact Engineering, 25(7): 631–639. https://doi.org/10.1016/S0734-743X(01)00004-5

Belov N, Yugov N, Kopanitsa D, Kopanitsa G, Yugov A, Kaparulin S, and Ustinov A (2016). Calculation of reinforced-concrete frame strength under a simultaneous static cross section load and a column lateral impact. In the AIP Conference Proceedings, AIP Publishing LLC, 1698: 040007. https://doi.org/10.1063/1.4937843

Bondarenko NA, Lyubimova TV, and Stogny VV (2020). Integrated assessment of potential geological risks in the Krasnodar Region. International Conference on GI Support of Sustainable Development of Territories, InterCartao. InterGIS, 26: 189–200. https://doi.org/10.35595/2414-9179-2020-2-26-189-200

Chen X, Chen C, Xu L, and Shao Y (2017). Dynamic flexural strength of concrete under high strain rates. Magazine of Concrete Research, 69(3): 109–119. https://doi.org/10.1680/jmacr.15.00548

Chiaia B, Kumpyak O, Placidi L, and Maksimov V (2015). Experimental analysis and modeling of two-way reinforced concrete slabs over different kinds of yielding supports under short-term dynamic loading. Engineering Structures, 96: 88-99. https://doi.org/10.1016/j.engstruct.2015.03.054

Davydchuk S and Dema D (2020). Analysis of the formation of financial resources of enterprises in united territorial communities. Scientific Horizons, 93(8): 39–46. https://doi.org/10.33249/2663-2144-2020-93-8-39-46

Demyanov A and Kolchunov VI (2017). The dynamic loading in longitudinal and transverse reinforcement at instant emergence of the spatial crack in reinforced concrete element under the action of a torsion with bending. Journal of Applied Engineering Science, 15(3): 377–382. https://doi.org/10.5937/jaes15-14663

Dong J, He X, Zhang H, Zhang J, Yang Y, Song Y, and Rao J (2017). Correlation analysis of accelerated aging and natural aging of GFRP in reinforced concrete beams. Journal of Wuhan University of Technology (Transportation Science and Engineering), 41(2): 312-317.

Galyautdinov Z (2018). Strength of tensed and compressed concrete segments in crack spacing under short-term dynamic load. In the MATEC Web of Conferences, EDP Sciences, 143: 01013. https://doi.org/10.1051/matecconf/201814301013

Galyautdinov ZR (2017). Deformation of reinforced concrete slabs on yielding supports under short-time dynamic loading. In the AIP Conference Proceedings, AIP Publishing LLC, 1800: 040002. https://doi.org/10.1063/1.4973043

Gao F, Wang M, Zhang X, He Y, and Li M (2017). A comment on the calculation models for reinforced concrete under intense dynamic loading. Baozha Yu Chongji, 37(2): 365–376.

He M, Zhang T, Ni C, Li Z, and Tao D (2020). Reliability based investigation into the duration of load effect for timber structure. Journal of Tongji University, 48(8), 1113–1121.

Kumpyak OG and Mescheulov NV (2017). Numerical simulation of yielding supports in the shape of annular tubes under static and short-term dynamic loading. International Journal for Computational Civil and Structural Engineering, 13(4): 103-113. https://doi.org/10.22337/2587-9618-2017-13-4-103-113

Kumpyak OG, Galyautdinov ZR, and Kokorin DN (2016). Strength of concrete structures under dynamic loading. In the AIP Conference Proceedings, AIP Publishing LLC, 1698: 070006. https://doi.org/10.1063/1.4937876

Li Y and Di Q (2011). Numerical simulation of dynamic characteristics of a cable-stayed aqueduct bridge. Earthquake Engineering and Engineering Vibration, 10(4): 569-579. https://doi.org/10.1007/s11803-011-0090-0

Likhov ZR, Dadova MK, Tokhaev GK, and Khussein AS (2020). To the calculation of reinforced concrete flexible elements with combined pre-stress, taking into account the complete diagrams of material deformation. In the IOP Conference Series: Materials Science and Engineering, IOP Publishing, 913: 022005. https://doi.org/10.1088/1757-899X/913/2/022005

Makhutov NA (2018). Actual problems of safety of critically and strategically important facilities. Factory Laboratory, Diagnostics of Materials, 84(1): 5–9. https://doi.org/10.26896/1028-6861-2018-84-1-I-05-09

Makhutov NA, Gadenin MM, Reznikov DO, and Neganov DA (2017). Analysis of stress-strain and limit states in extremely loaded zones of machines and structures. Chebyshev Collection, 18(3): 394–416. https://doi.org/10.22405/2226-8383-2017-18-3-394-416

Markush PP, Zavilopulo AM, and Shpenik OB (2018). Mass-spectrometry study of sulfur and selenium composition in gas-phase by electron impact. Scientific Herald of Uzhhorod University. 43: 63–74. https://doi.org/10.24144/2415-8038.2018.43.63-73

Melnyk N (2020). Biotethanol market model analysis and Ukraine biofuel exchange development. Scientific Horizons, 6(91): 101–115. https://doi.org/10.33249/2663-2144-2020-91-6-101-115

Mescheulov N, Kumpyak O, and Lyulevich Y (2017). Deformability of oblique sections of RC beams on yielding supports under dynamic impact. In the AIP Conference Proceedings, AIP Publishing LLC, 1800: 040006. https://doi.org/10.1063/1.4973047

Odnokopylov G and Bragin A (2014). Fault tolerant vector control of induction motor drive. In the IOP Conference Series: Materials Science and Engineering, IOP Publishing, 66: 012015. https://doi.org/10.1088/1757-899X/66/1/012015

Odnokopylov G and Bragin A (2015b). Mathematical model of brushless DC motor in phase loss operation mode. Applied Mechanics and Materials, 698: 24-29. https://doi.org/10.4028/www.scientific.net/AMM.698.24

Odnokopylov G and Rozayev I (2014). Formation of failure matrix and failure–free control algorithm for multi–sectioned Switched–reluctance drive. In the IOP Conference Series: Materials Science and Engineering, IOP Publishing, 66: 012035. https://doi.org/10.1088/1757-899X/66/1/012035

Odnokopylov GI and Bragin AD (2015a). Algorithms of fault tolerant control of induction motor electric drive in phase loss operate mode. In the International Siberian Conference on Control and Communications, IEEE Omsk, Russia: 1-5. https://doi.org/10.1109/SIBCON.2015.7147009

Odnokopylov GI and Rozayev IA (2015). Fault-tolerant control of switched-reluctance drive in emergency modes. In the International Siberian Conference on Control and Communications, IEEE, Omsk, Russia: 1-6. https://doi.org/10.1109/SIBCON.2015.7147192

Odnokopylov GI and Rozayev IA (2016). Fault-tolerant control algorithms of switched-reluctance motor drive in open-phase modes. In the 11th International Forum on Strategic Technology, IEEE, Novosibirsk, Russia: 140-144. https://doi.org/10.1109/IFOST.2016.7884212

Odnokopylov GI and Sarkisov DY (2017). Evaluation of breaking load parameters under shock wave loading for critical constructions of oil and gas sector facilities. Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, 328(3): 85-95.

Odnokopylov GI, Kumpyak OG, Galyautdinov ZR, and Galyautdinov DR (2019). Determination of vitality parameters of protected critical engineering structures under shock-wave loading. Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, 330(4): 110-125. https://doi.org/10.18799/24131830/2019/4/231

Odnokopylov GI, Sarkisov DYu, and Butuzov EA (2018). Assessment of the degree of survivability of critical building structures under shock-wave loading. Bulletin of the Tomsk Polytechnic University of Engineering Georesursov, 329(12): 122–135. https://doi.org/10.18799/24131830/2018/12/28

Orton SL, Jawdhari A, and Tian Y (2021). Effect of dynamic load redistribution in reinforced concrete flat-plate structures under collapse. Journal of Building Engineering, 44: 102688. https://doi.org/10.1016/j.jobe.2021.102688

Plevkov VS (1996). Dinamicheskaya prochnost'betona i armatury zhelezobetonnykh konstruktsii [Dynamic strength of concrete and rebar of reinforced concrete structures]. Tomsk Publishing House of State University of Architecture and Civil Engineering (TsNTI Publication), Tomsk, Russia.

Plevkov VS, Malganov AI, Baldin IV, Stukov PV, Kalachev KV, and Sarkisov DJ (2004). Estimation of operated ferro-concrete structures strength of usual and prestressed reinforcing under longitudinal forces, bending and twisting moments. In The 8th Russian-Korean International Symposium on Science and Technology, IEEE, Tomsk, Russia, 2: 342-344. https://doi.org/10.1109/KORUS.2004.1555642

Plevkov VS, Radchenko AV, Baldin IV, Radchenko PA, Goncharov ME, and Batuev SP (2013). Features of the destruction of reinforced concrete structures under dynamic loading. Vestnik Tambovskogo Gosudarstvennogo Tehnicheskogo Universiteta, 18(4): 1578–1579.

Plevkov VS, Sarkisov DY, and Tigay OY (2008). Investigation of reinforced concrete elements with oblique eccentric short term dynamic compression, stretching and bending. Izvestiya Orlovskogo Gosudarstvennogo Tekhnicheskogo Universiteta. Seriya: Stroitel Stvo i Transport, 3(19): 33-37.

Popov NN and Rastorguev BS (1980). Voprosy rascheta i konstruirovani-ya spetsialnykh sooruzheniy [Issues of calculation and design of special structures]. Stroyizdat, Moscow, Russia.

Sarkisov D, Gorlenko N, Gorynin G, Sarkisov Y, Izmailov G, and Shepelenko T (2020). Strength and deformability of reinforced concrete elements under oblique eccentric short-term dynamic compression, tension and bending. In the E3S Web of Conferences, EDP Sciences, 164: 14008. https://doi.org/10.1051/e3sconf/202016414008

Savinykh AS, Garkushin GV, Razorenov SV, and Kanel GI (2018). Method of measurement of the dynamic strength of concrete under explosive loading. International Journal of Fracture, 209: 109–115. https://doi.org/10.1007/s10704-017-0244-9

Venkiteela G, Sun Z, and Najm H (2013). Prediction of early age normal concrete compressive strength based on dynamic shear modulus measurements. Journal of Materials in Civil Engineering, 25(1): 30-38. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000528