Збірник наукових праць. Галузеве машинобудування, будівництво
Academic journal. Industrial Machine Building, Civil Engineering
http://journals.nupp.edu.ua/znp
https://doi.org/10.26906/znp.2026.66.4357

UDC 004.925.8;72.012

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Determination of the resistance of a residential building to progressive destruction under serial explosive loading using FEM-technology

Abstract. The stress state of deformation of building structures of a monolithic reinforced concrete residential block under shelling conditions was simulated using FEM technology in a nonlinear formulation and a conceptual model of the building was proposed that allows avoiding progressive destruction even during successive shell impacts on the most stressed areas of the load-bearing structures. Four FEM models of the building were analyzed: one initial model without damage and three models with the most stressed elements sequentially dismantled. The creation of new models was completed after reaching the stage of destruction of the final elements, i.e. after the beginning of the process of progressive destruction.

Keywords: finite element method technology, building, progressive destruction, load-bearing capacity

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Received: 14.03.2026 Accepted: 07.05.2026 Published: 31.05.2026

Introduction.

To restore the affected regions of Ukraine, it is necessary today to begin to develop new conceptual approaches in the field of construction, in particular in the construction of residential buildings of increased resistance to progressive collapse, which can be triggered by the action of explosive devices. The emergence of the topic of “progressive collapse” is associated with a number of tragic events, common to which was the factor of disproportionality between the cause (emergency event) and the magnitude of the final damage. With the main basic foreign and domestic literature from the history of emergence of subject of “the progressing collapse”, on firmness against the progressing collapse it is possible to get acquainted with examples of accidents of buildings and constructions, recommendations about methods of calculations in work [1]. The accumulated experience of destruction of buildings and constructions during war when construction civil objects are exposed savages to consecutive systematic firings and have to stage of final fracture, panel buildings from explosion of household gas and one-time terrorist blasting’s differ from experience about the progressing collapse enough, for example.

In LIRA-FEM the “progressing collapse” system which answers the existing recommendations for modeling of behavior of structures of buildings and constructions in case of emergency influences which cause local destructions of separate supporters is implemented [2]. In LIRA-FEM 2021, it is now possible to assign dT to elements of the “time off” scheme to simulate a local failure in a dynamic formulation. You can make this assignment to a single element (a column, for example) or a group of elements (a wall, for example).

The offered conceptual model of monolithic steel concrete residential unit differs in the increased rigidity rather from the monolithic buildings which are most extended to this time with the free planning scheme, especially from panel buildings. But it has big cost: safety needs additional expenses. We have the opportunity for the possibility of ensuring the preservation of the lives of residents of such residential buildings in the event of a repeat of hostilities with artillery shelling by savage neighbors.

Review of the latest research sources and publications

Analysis of the calculations showed that the proposed volumetric-spatial scheme of the building avoids the progressive collapse of the structure as a whole, even with the successive destruction of the three load-bearing walls. This gives some hope for the possibility of ensuring the preservation of the lives of residents of such residential buildings in the event of a repeat of hostilities with artillery shelling by savage neighbors.

The emergence of the topic of "progressive collapse" is associated with a number of tragic events, common to which was the factor of disproportionality between the cause (emergency event) and the magnitude of the final damage [3, 4]. In LIRA-SAPR 2021, it is now possible to assign dT to elements of the "time off" scheme to simulate a local failure in a dynamic formulation. You can make this assignment to a single element (a column, for example) or a group of elements (a wall, for example). In this case, impulse loads will be automatically generated, set in the direction opposite to the reactions of the removed elements. In nodes that remained "hanging" after the removal of elements (only deleted elements were adjacent to them), impulse loads will not be applied. Thus, it is enough to specify only the elements, the nodes do not need to be specified, which makes the task less time-consuming. The program sets the rest automatically: calculates the reactions of the removed elements and assigns impulses of influence (for all degrees of freedom, including rotary ones) [5, 6].

Theoretical aspects of progressive collapse analysis, calculation procedures, and the principal approaches adopted in international design standards to ensure the robustness and survivability of building structures are comprehensively discussed in the monograph by Starossek [7]. The book provides a systematic presentation of the mechanisms of progressive collapse together with analytical methods and design concepts for mitigating disproportionate structural failure.

Problem statement

Aggressive neighbors are not chosen, but it is necessary to promote their education. Yes, it takes time. 50 years passed between the establishment of the first successful high school in 1851 and the accession of Denmark to the economic elite. Norway and Sweden have made similar evolutions. Finland has generally passed in three decades [8]. At the same time, a policy of deterrence will be reliable only when there is an ability to refute any suspicions of weakness [9].

So, for a long time, our country has been living and fighting the aggressive influences of its northern neighbor. There is a process of constant destruction of buildings and structures. In many cases, damage to civilian objects is in the nature of a progressive collapse [10]. For example: the condition of buildings in Borodyanka [11] (Fig. 1) and in Severodonetsk [12] (Fig. 2).

Figure 1 – Condition of a residential building in Borodyanka

Figure 2 – Condition of a residential building in Severodonetsk

To restore the affected regions of Ukraine, it is necessary today to begin to develop new conceptual approaches in the field of construction, in particular in the construction of residential buildings of increased resistance to progressive collapse, which can be triggered by the action of explosive devices. Attracting centuries of historical experience in construction can lead architects and engineers to create reliable structures: History is an unending dialogue between present and the past, that's why few pages of history give more insight than all the metaphysical volumes (Fig. 3) [13].

Figure 3 – The Crypt of San Magno, Anagni, Italy.

The goal of the research is creation of a BIM-concept model of a residential building that will be able to withstand serial explosive loads on load-bearing building structures without progressive collapse of the structure as a whole.

Basic material and results

The basis for the construction of the volumetric-spatial scheme of the building is the principle of "double walls": that is, the creation of residential premises is located at least behind two load-bearing reinforced concrete walls.

The study was conducted with the involvement of modern BIM-technologies from the company LIRALAND Group [14] SAPFIR-3D and LIRA-SAPR in the following sequence:

2.1. Creation of BIM-model of residential building "KVITKA 6 eng.spf" in SAPFIR-3D and FEM-model "KVITKA 6 eng.lir" calculation in LIRA-FEM in linear setting for action:

2.1.2. static loads from own weight of building structures, operational from people and equipment, from soil and wind;

2.1.3. dynamic seismic load.

2.2. Calculation of the FEM-model of the residential building "KVITKA 6 eng_N.lir" in a nonlinear formulation in a step-by-step mode, considering real diagrams of concrete and reinforcement in the STAGES LIRA-FEM system for static loads.

2.3. Calculation of FEM-models of residential building "FLOWER 6 eng_N Dt 1.lir", "FLOWER 6 eng_N Dt 2.lir" and "FLOWER 6 eng_N Dt 3.lir" in dynamics in time in step-by-step mode in the COLLAPSE LIRA-FEM system for three consecutive local collapses, considering the previous ones.

The following figures show the results of modeling and calculations of models:

BIM-model „KVITKA 6 eng.spf" (Fig. 4-6);

FEM-model „KVITKA 6 eng.lir" (Fig. 7-8);

FEM-model „KVITKA 6 eng_N.lir" (Fig. 9-11);

FEM-model „KVITKA 6 eng_N Dt 1.lir" (Fig. 12-15);

FEM-model „KVITKA 6 eng_N Dt 2.lir" (Fig. 16-19);

FEM-model „KVITKA 6 eng_N Dt 3.lir" (Fig. 20-24).

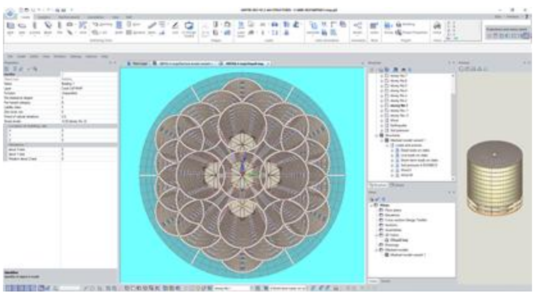

Figure 4 – General form: BIM-model „KVITKA 6 eng.spf". Perspective view from above (floor slabs are not conditionally shown).

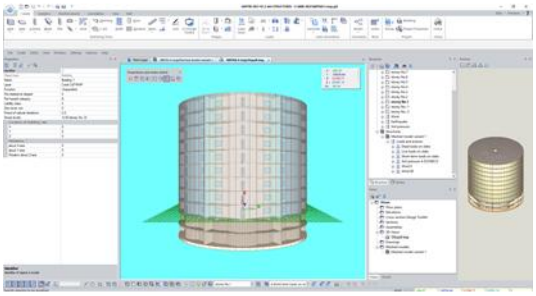

Figure 5 – General form: BIM-model „KVITKA 6 eng.spf". Perspective front view.

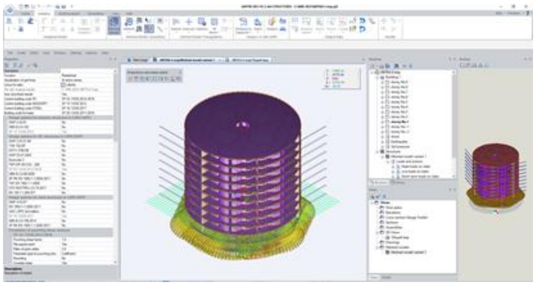

Figure 6 – Meshed model: BIM-model „KVITKA 6 eng.spf".

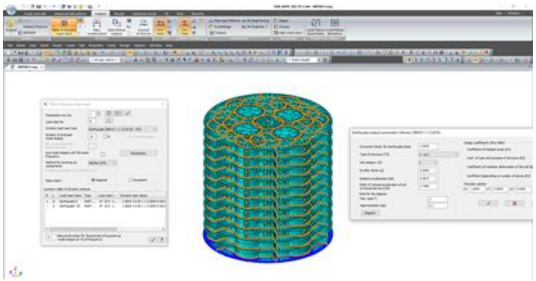

Figure 7 – Calculation model: FEM-model "KVITKA 6 eng.lir".

Figure 8 – The result of the calculation: FEM-model "KVITKA 6 eng.lir".The third mode shape, considering the seismic load.

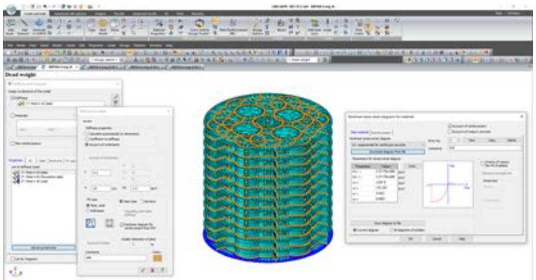

Figure 9 – Calculation model: FEM-model "KVITKA 6 eng_N.lir".

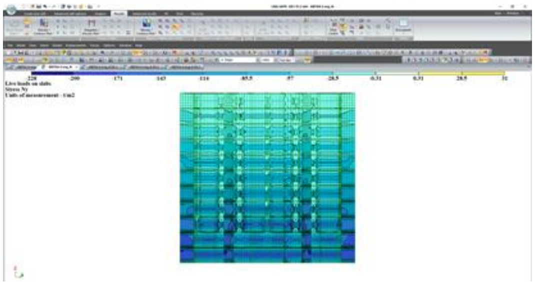

Figure 10 – The result of the calculation: FEM-model "KVITKA 6 eng_N.lir". Live loads on slabs. Stress Ny.

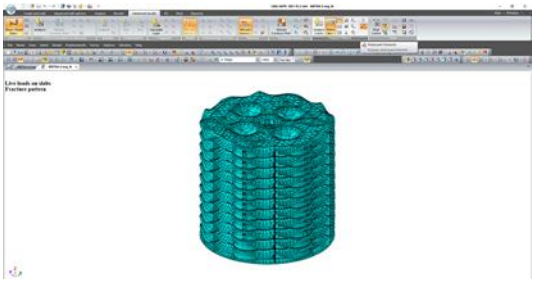

Figure 11 – The result of the calculation: FEM-model "KVITKA 6 eng_N.lir". Live loads on slabs. Compute parameters of cracks.

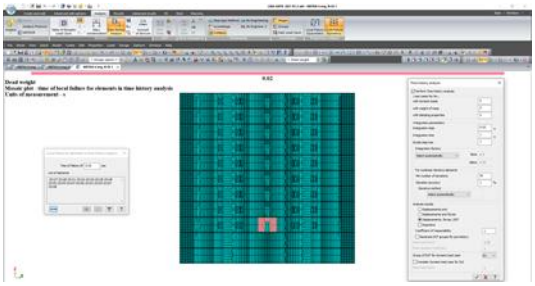

Figure 12 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 1.lir". Local failure for elements in time history analysis.

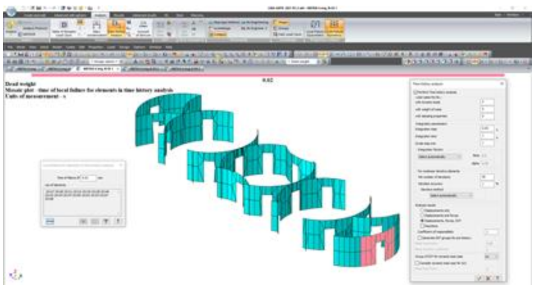

Figure 13 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 1.lir". Local failure for elements in time history analysis: Location scheme № 1.

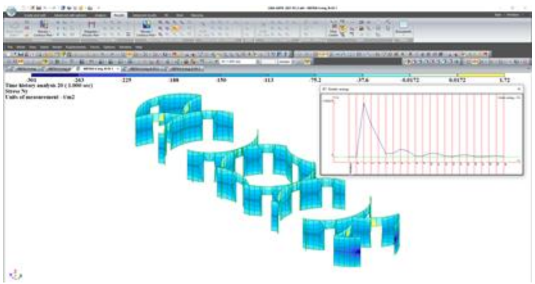

Figure 14 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 1.lir". Live loads on slabs. Stress Ny. Kinetic energy.

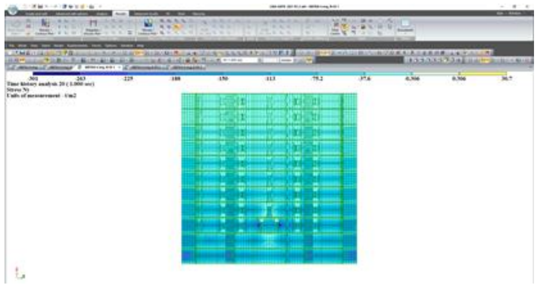

Figure 15 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 1.lir". Live loads on slabs. Stress Ny. General view of the model.

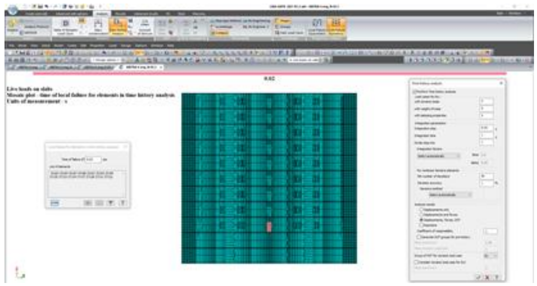

Figure 16 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 2.lir". Local failure for elements in time history analysis.

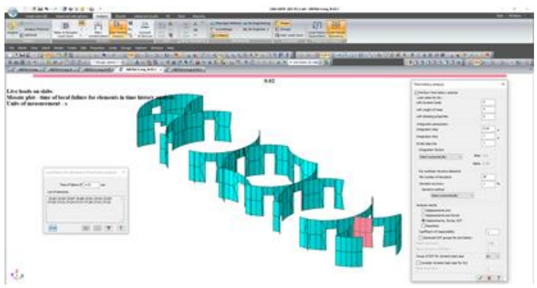

Figure 17 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 2.lir".Local failure for elements in time history analysis: Location scheme № 2.

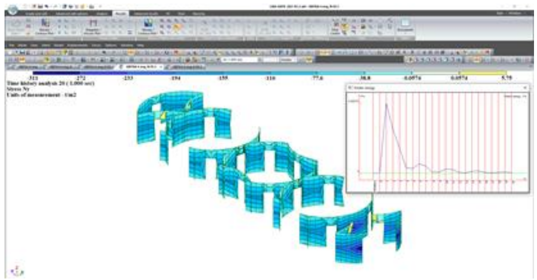

Figure 18 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 2.lir". Live loads on slabs. Stress Ny. Kinetic energy.

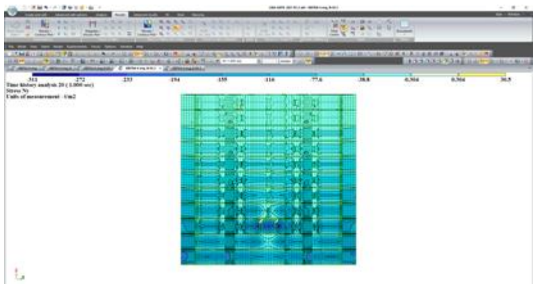

Figure 19 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 2.lir". Live loads on slabs. Stress Ny. General view of the model.

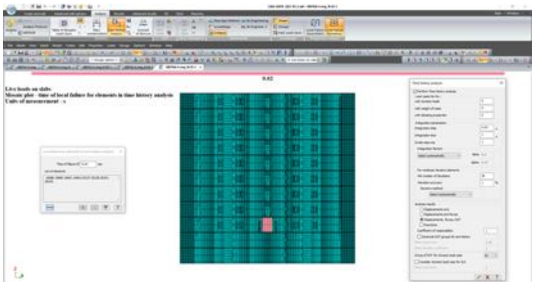

Figure 20 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 3.lir". Local failure for elements in time history analysis.

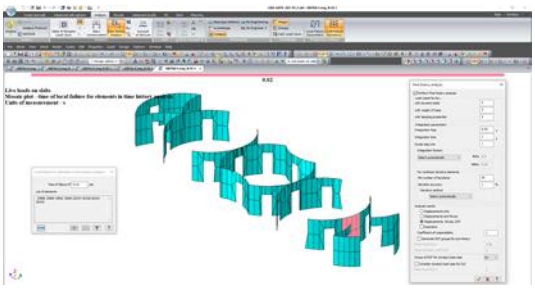

Figure 21 – Calculation model: FEM-model "KVITKA 6 eng_N Dt 3.lir". Local failure for elements in time history analysis: Location scheme № 3.

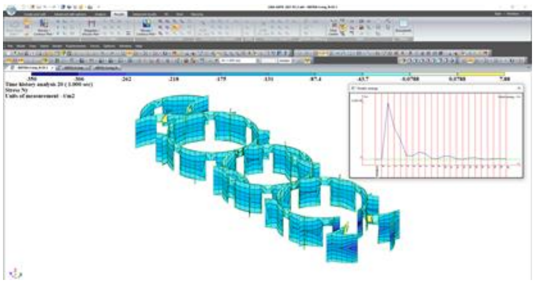

Figure 22 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 3.lir". Live loads on slabs. Stress Ny. Kinetic energy.

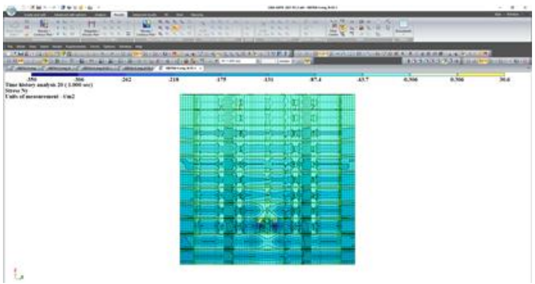

Figure 23 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 3.lir". Live loads on slabs. Stress Ny. General view of the model.

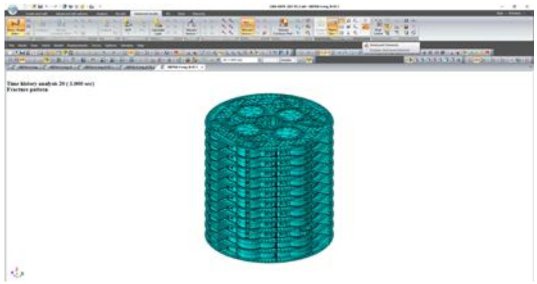

Figure 24 – The result of the calculation: FEM-model "KVITKA 6 eng_N Dt 3.lir". Live loads on slabs. Compute parameters of cracks.

The intense state of strain of building constructions of monolithic steel concrete residential unit in the conditions of shelling by means of FEM-technology in nonlinear statement on four FEM-models is analyzed:

1. "KVITKA 6 eng_N.lir": initial FEM-model without damages;
2. "KVITKA 6 eng_N Dt 1.lir": FEM-model with the dismantled most intense elements of external load bearing walls according to work of initial model;
3. "KVITKA 6 eng_N Dt 2.lir": FEM-model with the dismantled most intense elements of internal load bearing walls according to work of the second model;
4. "KVITKA 6 eng_N Dt 3.lir": FEM-model with the dismantled most intense elements of internal load bearing walls according to work of the third model.

The analysis it has been complete after achievement of limit stage that is destruction of one of final elements. The main results of the calculations are given in the Table 1.

Conclusions

Analysis of the results of calculations of FEM-models "KVITKA 6 eng_N" showed:

4.1. The proposed volumetric-spatial scheme of the building avoids the progressive collapse of the structure as a whole, even with the successive destruction of the three load-bearing walls.

4.2. We have the opportunity for the possibility of ensuring the preservation of the lives of residents of such residential buildings in the event of a repeat of hostilities with artillery shelling by savage neighbors.

4.3. Of course, residential buildings of this type have a larger estimate than modern ones: two floors for a bomb shelter, double and triple protective external reinforced concrete walls, increased consumption of reinforcement and concrete.

Table 1 – The main results of calculations of FEM-models «KVITKA 6 eng_N»

№	BIM-models	Stress N_y min, t/m^2	Stress N_y max, t/m^2	Amplitude of kinetic energy, t*m	Number of finite elements destroyed
1.	"KVITKA 6 eng_N.lir"	-228,00	31,00		0
2.	„KVITKA 6 eng_N Dt 1.lir"	-301,00	1,72	0,000275	0
3.	„KVITKA 6 eng_N Dt 2.lir"	-311,00	5,75	0,000151	0
4.	„KVITKA 6 eng_N Dt 3.lir"	-350,00	30,6	0,000149	1

But we already have a practical, numerous and quite tragic experience in the destruction of our cities and towns. Therefore, we consider it expedient to introduce this type of building, at least when restoring border towns to ensure the safest possible accommodation for the families of our servicemen.

4.4. This type of building, unfortunately, will be relevant for quite a long time: the period of successful implementation of bildung in the Scandinavian countries took 50 years. And there is no hope that the last northern invasion cannot be hoped for. Therefore, we need to build reliable residential buildings with ensuring their resistance to progressive collapse.

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Визначення стійкості житлового будинку до прогресуючого руйнування при серійному вибуховому навантаженні з використанням МСЕ-технології

Аннотація. За допомогою технології методу скінченних елементів (МСЕ) у нелінійній постановці було змодельоване напружено-деформований стан будівельних конструкцій монолітної залізобетонної житлової будівлі в умовах обстрілу та запропоновано концептуальну модель будівлі, яка дозволяє уникнути прогресуючого руйнування навіть під час послідовних ударів снарядів по найбільш напружених ділянках несучих конструкцій. Було проаналізовано чотири МСЕ-моделі будівлі: одну початкову модель без пошкоджень та три моделі з послідовно демонтованими найбільш напруженими елементами. Створення нових моделей було завершено після досягнення стадії руйнування кінцевих елементів, тобто після початку процесу прогресуючого руйнування.

Ключові слова: технологія методу скінченних елементів , будівля, прогресуюче руйнування, несуча здатність

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Надіслано до редакції:	14.03.2026	Прийнято до друку після рецензування:	07.05.2026	Опубліковано (оприлюднено):	31.05.2026

Suggested Citation:	
APA style	Chernih, O., Sokolenko, K., & Sokolenko, V. (2026). Determination of the resistance of a residential building to progressive destruction under serial explosive loading using FEM-technology. *Academic Journal. Industrial Machine, Building Civil Engineering*, *1*(66), 57-63. https://doi.org/10.26906/znp.2026.66.4357
DSTU style	Chernih O., Sokolenko K., Sokolenko, V. Determination of the resistance of a residential building to progressive destruction under serial explosive loading using FEM-technology. *Academic journal. Industrial Machine Building, Civil Engineering.* 2026. Vol. 66, iss. 1. P. 57–63. URL: https://doi.org/10.26906/znp.2026.66.4357.