The research of a building covering spatial truss resistance to the progressive destruction in modern CAE-systems

To cite this article: V Alpatov and M Balzannikov 2018 IOP Conf. Ser.: Mater. Sci. Eng. 456 012011

View the article online for updates and enhancements.
The research of a building covering spatial truss resistance to the progressive destruction in modern CAE-systems

V Alpatov and M Balzannikov
Samara State Technical University, Russia, 443110 Samara, Molodogvardeyskaya street, 244
avu75@mail.ru

Abstract. Modern methods of calculating building structures for progressive collapse expect to carry out a calculation with a change in the design scheme. Change of the design scheme is carried out, for example, by excluding one or more elements from it. The calculation of the scheme remaining part for "viability" is performed after the removal of the elements. The calculation is realized in the form of an iterative process. Each subsequent result, leading to the some of the elements exclusion from the calculation scheme, increases the amount of the whole system destruction. For today there are recommendations of calculations performance on a progressing collapse in the literature. In practice, engineers have to perform a qualitative analysis of the system to remove elements from the design scheme. In this paper, we present the results for solving this problem for the metal framework of a production building with a spatial structural coverage. Solving the problem, the authors used the calculating applications Lira, SCAD, STAAD, VisualAnalysis and SAP 2000. The modeling of the fracture process was preceded by the possible damage analysis to the coating elements when the source location of ignition inside the building was changed. For the focus of the fire, the rack position for storing the finished products was taken. In order to detect the most dangerous places of fire’s origin, the authors used the graphical overlay method of the technological scheme for the construction scheme. In the fires places, areas of structural damage were identified. In this way, the elements (an element) of the construction were determined, which should be removed first from the design scheme. The conducted research of structural design showed that local emergency influence on the majority of structural elements (excluding the nodes transferring the load to the capitals) does not lead to further destruction of the spatial lattice structure elements. The authors confirmed the well-known fact that a redistribution of forces between neighboring elements occurs for statically indeterminate structures in the event of an individual element failure. The calculations showed that the cross-section of the element, selected according to the maximum values of forces, non-accidental combinations is able to withstand the load in an emergency situation.

1. Introduction
Modern methods of calculating building structures for progressive collapse expect to carry out a calculation with a change in the design scheme [1–20]. Change of the design scheme is carried out, for example, by excluding one or more elements from the design scheme. After the removal of the elements, the calculation of the scheme remaining part for "viability" is performed. If the remaining circuit is capable of withstanding the current loads, then a conclusion is made about its resistance to progressive collapse. If it did not, the calculation would be continued. The following elements are removed from the circuit, unable to withstand the load. Thus, a new design scheme is formed for the
next calculation. Analysis of the updated scheme calculation can lead to one of the following conclusions:
1. The new design scheme is able to withstand the current loads;
2. Some of the new design scheme elements are outside the permissible work.

When the last result is received, the next attempt is made to correct the calculation scheme. The calculation is realized in the form of an iterative process. Each subsequent result, leading to the exclusion of some elements from the calculation scheme, increases the amount of the system destruction as a whole. The iterative process can end with one of two conclusions:
1. A system with remotely elements proved to be capable of perceiving loads;
2. The system completely degenerated, that is, disappeared.

The last conclusion indicates a complete (total) destruction of the system. Such a system is not resistant to the progressive collapse development. The first conclusion shows that the system ceases to collapse at some stage of the calculation. Here, we may get one of two consequences:
1. A significant part of the original system is destroyed;
2. A small part of the initial system is destroyed.

In the first case, the collapse is of a global nature. In the second case, the collapse can be referred to local or global. The criterion of global collapse is the ratio of the destroyed part of the structure to the original volume.

In the described technique there are two "weak" places:
1. Unreasonable selection of the first element for removal from the original calculation scheme;
2. Unfounded sign of the system global destruction.

Nowadays, there are recommendations of calculations performance on a progressing collapse in the literature [1-7]. However, as a rule, they are of a private nature and do not allow to solve the problems of the "weak" places of the methodology.

In practice, engineers have to perform a qualitative analysis of the system to solve this problem. As a result of such analysis, a subjectively substantiated decision is made on the "first" remote element and on the magnitude of the global destruction criterion for each specific case. The calculations of systems for progressive collapse can be performed in various ways. At the present stage of computer technology development it is recommended to use specialized software systems [21]. The authors used the calculated complexes - Lira, SCAD, STAAD, VisualAnalysis, SAP 2000 [22, 23] to solve the problem presented in this paper. The use of several computational complexes was justified by the authors' desire in their studies to exclude the influence of possible program errors on the final result.

The object of the study was the metal frame of the building with a coating in the form of a large-span space latticed plate (Figure 1).

2. Materials and methods
Metal structural slabs of coatings have proved themselves in buildings with large spans [24–36]. According to the modern standards of many countries, large-span structures should be safe, including in relation to the development of avalanche (progressive) collapse in emergency operations [1–9].

Structures have multiplied static indeterminacy, so an element removing from the calculation scheme does not necessarily lead to a loss of the system’s geometric stability [34–36].

A good resistance to progressive deterioration is initially expected from structural coatings. At the same time, any element removing from the system, without fear of its death is impossible. Not all elements of the structural coating plate are permissible to remove. For the frame of the building, which has a metallic coating structure, it is impossible to distinguish the elements that are inadmissible for removal a priori. Some of the elements, for example, columns are obviously unacceptable to removal. Introduce the failure of these elements does not make sense, so all of these will lead to the complete or significant destruction of the framework. With the respect to the other elements, the task of studying effect of their removal on the possible progressive destruction of the framework is urgent. It is possible to distinguish elements "necessary" and "superfluous" inside the structural plates [25]. The failure of a "necessary" elements leads to the destruction of the system. Failure of the "superfluous"
element can lead to redistribution of efforts on neighboring elements. This will change the design scheme, but the system itself remains intact.

![Figure 1. Object of study.](image1)

1 – Mesh of lower belt elements; 2 – Mesh of upper belt elements; 3 – Diagonal braces; 4 – Column capitellum; 5 – Column; 6 – Top node; 7 – Lower node.

![Figure 2. Technological scheme of the building.](image2)

![Figure 3. Constructive scheme of building cover.](image3)

Considering the presence of many elements in the structural construction, the conclusion arises need to perform multiple calculations with the determination of the collapse scale from each remote element. The scale of the collapse should be taken into the task in relative units, for example, as the ratio of the caving area to the total area of the cover. Then, one can attribute the result to either a local (acceptable solution) or global collapse (an unacceptable solution) by entering a numerical criterion for estimating the collapse scale (for example, 10–15%).

This approach was implemented by the authors in the calculation simulation of the emergency situations of the production building frame from fire damage. The extent and area of damage to the structure of the coating from various fires was determined. The modeling of the fracture process was
preceded by an analysis of possible damage to the coating elements when the source of ignition inside location in the building was changed by its calculation. For the focus of the fire, the rack position for storing the finished products was taken (Figure 2).

Figure 4. Places of fire dangerous origin. 1 – The effect of fire on one element; 2 – The effect of fire on a group of elements.

To detect the most dangerous places of the fire’s origin (Figure 4), the authors used the method of graphical overlay of the design scheme (Figure 2) for the constructive scheme (Figure 3). In the places of found fires, areas of structural damage were identified. In this way, the elements (an element) of the construction were determined, which should be removed first from the design scheme. When modeling an emergency, it was assumed that the occurrence of a fire occurs on the stillage. The problem was formulated as variable, as the local ignition possibility of each stillage separately was considered. Analysis of the structural elements position in relation to the appearance of possible fire sources allowed identifying options limited number for the exclusion of elements from the design scheme. Qualitative analysis of the possible pattern of destruction of the coating from the fire allowed to make a calculations sequence of the system on the computer. In the process of an emergency situation modeling, the following restrictions were taken:

1) Only those elements that are located in the area of the proposed fire site are exposed to the temperature effect (Figure 4).
2) Only the bottom belt of the structural plate can be directly exposed to fire (Figure 1, 5).
3) The fire effect on the elements (line, node or group of rods) disables them, which is modeled as an exclusion of the element from the calculation circuit.

Figure 5. Scheme of fire impact on the object of research. 1 – The effect of fire on one element; 2 – The effect of fire on a group of elements.
The conducted research of structural design showed that local emergency influence on the majority of structural elements (excluding the nodes transferring the load to the capitals) does not lead to further destruction of the spatial lattice structure’s elements. The authors confirmed the well-known fact that for statically indeterminate structures in the event of an individual element failure, a redistribution of forces between neighboring elements occurs. The calculations showed that the cross-section of the element, selected according to the maximum values of forces non-accidental combinations, is able to withstand the load in an emergency situation. The failure of any rod or assembly not connected with the capital of column does not entail an avalanche collapse of the structure (Figure 6).

![Figure 6. Calculation scheme with a site of local destruction.](image)

3. Conclusions
The following established results are:

1. The failure of any column element (including elements of column capitals) leads to a complete avalanche collapse of the entire frame of the building;
2. The largest part of the local collapse is about 2% of the system total area;
3. Metal structural cover plates are not prone to progressive collapse;
4. The choice of the calculation complex for the analysis of building structures on the resistance to the development of progressive collapse with the help of a computer does not affect the final result of the calculation.

References
[1] STO 008-02495342-2009 Prevention of the Progressive Collapse of Reinforced Concrete Monolithic Structures of Buildings. Design and Calculation 2009 (Moscow: ACU) p 20
[2] Eurocode 0. Basic of Structural Design: EN 1990:2001 2001 (Brussels: European Committee for Standardization)
[3] UFC UFC 4-023-03 Design of Buildings to Resist Progressive Collapse 2005 (USA)

[4] Design Regulations of Swedish Board of Housing, Building and Planning 2000 (Swedish Board of Housing, Building and Planning) p 187

[5] UFC3-340-01 Design and Analysis of Hardened Structures to Conventional Weapons Effect 2002 (Washington: Dep. of Defense)

[6] ASCE 7-02 Minimum Design Loads for Buildings and Other Structures 2000 (Reston: ASCE)

[7] BS5950-1:2000 Structural Use of Concrete, Part 1. Code of Practice for Design and Construction 1998 (London: Cheswick High Road)

[8] Grachev V, Vershina T, and Puzatkin A 2010 Disproportionate Destruction. Comparison of Calculation Methods (Yekaterinburg: Azhur) p 81

[9] Tur V 2009 Bull. Polotsk State Univ. 6 2–14

[10] Menczel K 2009 Progressive Collapse: Comparison of Main Standards, Formulation and Validation of New Computation Procedures: diss. D. Eng. p 122

[11] Vlassis G 2007 Progressive Collapse Assessment of Tall Buildings (London) p 416

[12] Aydemirov K 2010 Bulletin Of Dagestan state technical University 18 117–30

[13] Kholopov I, et al. 2008 Building materials, equipment, technologies of the 21st century 1 108–66–8

[14] Tour V, Tour A, Markovsky D Building science and technology 6 11–27

[15] Park S 2004 International Journal of Solids and Structures 41 4035–5050

[16] Starossek U 2007 Engineering Structures 9 2302–307

[17] Li H, Yen C 1995 Fuzzy Sets and Fuzzy Decisions (New York: CRC Press) p 80

[18] Perelmutter A 2007 News of Orel State Technical University 2/14 160–69

[19] Kudishin Yu, Drobot D 2008 Metal buildings 1 20–23

[20] Gordeeva T, Belomytteva N 2015 Traditions and innovations in construction and architecture. Natural sciences and technospheric security a collection of articles (Samara: SSUCE) pp 406–10

[21] Alpatov V, and Kareev D 2013 Collection of reports of the scientific and practical conference dedicated to the 100th anniversary of the birth of Professor E.I. Whitening (Moscow: MGSU) pp 12–16

[22] Alpatov V, Lukin A, and Petrov S 2014 Industrial and Civil Engineering 3 47–51

[23] Alpatov V 2014 Procedia Engineering 91 177–82

[24] Alpatov V, and Lukin A 2014 Procedia Engineering 91 177–182

[25] Alpatov V, and Lukin A 2015 Procedia Engineering 111 20–9

[26] Alpatov V 2016 MATEC Web Conf. 86 02005

[27] Alpatov V 2016 MATEC Web Conf. 86 02020

[28] Belostotsky A, Dubinsky S, et al. 2013 International Journal for Computational Civil and Structural Engineering 9 42–7

[29] Ruzhansky I 2010 Industrial and Civil Engineering 5 12–15

[30] Gogolkina O 2018 Architecture and Modern Information Technologies 1 355–63

[31] Semenov V 2010 Bulletin of the Kyrgyz-Russian Slavic University 2 165–71

[32] Generalov V, Generalova E, et al. 2018 E3S Web of Conferences 33 01020

[33] Generalov V, Generalova E, et al. 2018 E3S Web of Conferences 33 01021

[34] Gorokhov E, Mushchanov V, et al. 2015 Metal Structures 4 191–06

[35] Trofimov V, Begun 1972 B Structural Structures (Research, Calculation and Design) (Moscow: Stroiizdat) p 155

[36] Mushchanov A, Mushchanov V, et al. 2016 Constr. Unique Buildings Struct. 2 18–29