The Systems of Reservation of Bearing Structures Coatings of Transport Buildings and Constructions for Northern areas

V Egorov¹, M Abu-Khasan¹, V Shikova¹
¹Emperor Alexander I St. Petersburg State Transport University, St. Petersburg, Moskovsky prospect, 9, 190031, Russia

E-mail: pgups1967@mail.ru

Abstract. At design supporting structures for coatings of transport buildings and structures for northern areas in accordance with regulatory requirements, their resistance to progressive (chain) collapse is determined. To ensure safety, the structural system of the building in the northern areas must ensure its durability and stability, at least for the time necessary to evacuate people. To improve the reliability of the supporting structures of coatings proposed, developed and researched the system of redundancy of the type-sprengel. The scenario of collapse and an algorithm for calculating the intact elements of the coating system are proposed. The results of the study are given, which indicate that by varying the rigid parameters of the backup system it is possible to achieve minimal damage from the collapse of individual elements of the system.

1. Introduction

The history of occurrence of the term "progressing collapse" and possible ways of prevention of its emergence in the northern areas.

Among the main properties that must be possessed by buildings and structures is “survivability”. Under the survivability refers to the property of the object to maintain a limited performance under the effects not stipulated by the operating conditions, or the property of the object to maintain a limited performance in the presence of defects or damage of a certain type, as well as the failure of some components.

The term “progressive collapse” and the formulation of the problem of protection against it (understood as an analogue - “survivability”) of buildings arises in 1968 in the report of the commission investigating the causes of the accident at the 22-storey Ronan Point residential building in Lon-don [1-2].

After the publication of the report, in almost all developed countries, studies of this problem were initiated, and by the end of the 70th years an analysis of possible means of protection against the progressive collapse of buildings of various structural systems, taking into account economic indicators, was largely completed [3-4].

The main conclusions drawn by various researchers and the changes that followed the other’s design standards of other countries (mostly Western European states) turned out to be similar. During the subsequent development of parameters for rationing the level of protection of buildings and structures from such situations, another term “disproportionate destruction” which is characterized by the volume and the area of the building which can collapse during the destruction or failure of (any) each individual carrier element.
Currently, this is the value of disproportionate destruction in the form of the permissible total square near the site of local destruction of the element, which is normalized in European countries - in Eurocodes and relevant national standards, construction laws and construction codes [5-6].

At the moment, the main documents describing solutions to the current issue of progressive destruction throughout the world are:
- United Kingdom - BS 5950 2001, BS 8110 2005a, 2005b, BS 5628 2005;
- Eurocode - EN 1990, EN 1991-1-7;
- Canada - NBCC;
- USA - ACI 318, GSA 2003, DOD 2005;
- RF - recommendations for the protection of buildings and structures. Since 2017, a set of rules “protection of buildings and structures from progressive collapse” has been developed.

Also, with regard to the Russian practice of recent years in the regulatory and methodological literature is mainly used only the term "protection from progressive collapse" and does not provide other possible approaches to ensure the reliability of buildings and structures. In the listed regulatory documents there is no uniform approach to defining the problem and forming possible solutions, but the following provisions unite all the listed standards:
- all the supporting elements that form the building system should be resistant to collapse after the local collapse of individual elements of the system under different environmental or any other nature;
- local destruction of individual structures of the system is possible, but the redistributed load must be perceived by the remaining elements of the system without the danger of their destruction;
- the constructive system of the building must ensure its durability and stability, at least for the time necessary for evacuation of people;
- calculation on the progressing (avalanche) destruction is carried out on a special combination of loads and impacts (permanent and temporary long-term loads). Load reliability factors should be taken to be 1.

2. Methods
Methods for assessing the degree of damage or the operational suitability of structures throughout in the northern districts are somewhat different, in some documents the area of damaged floor structures is limited; in others, the state of the structures that have not left work is assessed; as well as the economic benefits of building a new one or restoring an old building [7-8].

The main means of a building from progressive collapse is a method of reservation the strength of load-bearing structures, ensuring the bearing capacity of the elements of a framework of the building (structures of coatings and floors, structure nodes, creating continuity and continuity of floor reinforcement, etc.).

As mentioned above, reservation is a method of increasing the reliability of an object by installing additional elements that exceed the minimum required for the normal execution by the object of its functional purpose. In this case, the system failure occurs only if the main and all backup elements fail. The system of reservation can be represented from a number of stages, each of which performs certain functions of the system. The task of redundancy is to find such a number of backup samples at each stage, which will provide a given level of reliability of the system at the lowest cost [9-10].

3. Results and discussion
The proposed technical solution:
There is a number of technical solutions which application allows to increase viability of the carrier systems in the conditions of collapse. The following new technical solutions which can help to increase bearing capacity of a framework of the one-storey industrial building [11-12].

The frame of a one-storey industrial building includes single-span frames, a system of vertical and horizontal stiffness links. The frames consist of columns and rigels, which are truss. Neighboring frames are interconnected by a system of horizontal and vertical cover links. In addition to the structurally designed communication systems and spacers of the coating, additional ties are established.
along the upper belt of the trusses along the perimeter of the building, forming a closed rigid contour (Figure 1).

Figure 1. The plan of the industrial building and the scheme of elements of reservation.

This goal is achieved by the fact that the trusses are connected between themselves with spacers and puffs, which are fastened through sliding racks with the possibility of slipping to the struts of the upper belt of the trusses, and to the trusses themselves at the points of their mutual intersection [13-14].

The reservation system can be represented as a core system with shearing bolts or with bursting inserts.

Due to the presence of these signs, the expected effect is achieved, which consists in the fact that with progressive collapse, when one of the trusses of the building frame is destroyed (figure 2), under the action of the weight of the truss, a load is transferred to the rope (tightening) and a shear bolt is cut (for the first system of reservation), or the bolt joints of the core system with a discontinuous liner "along the chain" and the loss of stiffness of the liner itself (for second version of the system of reservation), the truss falls onto the rope, which absorbs the weight of the truss with the overlying structures. This will prevent the fall of structures on people and equipment [15-16].
4. Calculation of the proposed system

For convenience of calculation, we replace the system of reserved racks with a system consisting of springs.

The elastic work of the safety tightening will be presented in the form of springs with equivalent rigidity equal to

\[ c(x) = \frac{EA_t}{l_t} \]

where \( E \) is the modulus of elasticity of tightening, N/m²;
\( A_t \) - is the cross-sectional area of a tightening, m²;
\( l_t \) - puff length, m

To find the speed and length, each tightening is considered separately, and the final data obtained in the calculation for the previous spring will be initial for the subsequent ones.

The potential energy with a vertical downward movement is:

\[ E = mgh, \]

where \( m \) is the mass of the truss, kg;
g - acceleration of gravity, m/c²;
h - free fall of the truss, m

The potential energy of a deformed body is

\[ E_p = \frac{c(x)h^2}{2}, \]

where \( c(x) \) is the rigidity of the safety tightening, N/m;
h - elongation, m
The calculation is carried out in stages (Figure 3):
1) The beginning of the fall of the truss (a segment AB).
2) The work is included insuring tightening and bolted connection (a segment BC).
3) Free fall truss (a segment CD).

Consider the scenario of progressive collapse of truss structures (trusses) of a one-story industrial building in the middle span of a building:

When performing the calculations, the following parameters of the one-storey industrial building were assumed: the span of the building 24, m, the column pitch in the longitudinal direction is 6.0 m, the length of the building is 48.0 m.

The graph in Figure 4 shows the change in the truss fall rate in the middle span of the building [17-18].

After the destruction of floor structures, the truss freely falls with constant acceleration (in Figure 4 it is the blue curve, indicated by the Roman numeral II) until the safety tightening is turned on in this section in Figure 4 is marked by a curve A.

Further, the safety tightening gets into gear with initial speed which the truss developed during free fall before the onset of this stage (in the figure this stage is designated by Roman I), this section can be called the section of elastic resistance to movement. The speed during the elastic work of an tightening depends on the rigidity of the tightening (c(x)), and how far the tightening will stretch to the loss of its rigidity (∆h
el
)
[19-20].

From the analysis of Figure 4 it follows that the speed of the falling trusses decreases as the safety tightening starts to impede the free fall.
Figure 4. Graph of the final speed when using the reservation system (line A), speed changes with the free fall of the truss (curve B).

In figure 5 shows the change in kinetic energy since the moment when the reservation system was turned on, it can be seen that the speed on the stretch of elastic movement decreases, which means that the kinetic energy decreases and its absorption occurs.

When the spring quite exhausted completely the rigidity, the entire load from the falling truss is transferred to the bolt in the rack of the reservation system and when the load exceeds the strength of the bolt’s shear strength, the truss free fall again and the speed increases, and the acceleration reaches 9,81 m/s². The cycles are repeated until the truss does not fall on the floor structure, or it stops at some distance from the floor.

In this case, with the destruction of the truss in the middle span of the building with the given parameters, the truss fell down to a distance of 5.4 m and stopped (v_{terminal} = 0, a = 0, E = 0). The average fall rate is equal to 3,6 m/c², the average acceleration value is 3,35 m/c², the average value of the kinetic energy is 17917 Joule. The calculation was performed in the Mathcad system.

Figure 5. Graph of kinetic energy changes when a truss falls when using the reservation system (curve A), energy changes at a truss free fall (curve B).
5. Conclusions
1. In each case, when the reservation system is turned on during the fall of the truss, there is a decrease in such movement parameters as speed, acceleration due to the elastic work of the safety tightening and shearing bolt in the strut, compared to the free fall of the truss.

2. When the reservation system is put into operation, the kinetic energy decreases (it is “absorbed” by braking the falling truss), which leads to a decrease in the dynamic effect on the environment from the fall of the truss.

3. The main advantage of this reservation system in the northern areas is that when selecting such characteristics as: the length of the safety tightening, the rigidity of the safety tightening, the diameter and number of bolts in the strut, you can achieve that the speed of the falling truss is not just reduced to the moment of contact with the floor structure, but can turn to zero, that is, the truss will stop at some distance from the floor. This will give the opportunity and time to at least evacuate people, and this is the main idea of the reservation system.

References
[1] Franzoni L, Lebée A, Lyon F, Forêt G 2018 Closed-form solutions for predicting the thick elastic plate behavior of CLT and timber panels with gaps Engineering Structures 164 pp 290-304 DOI: 10.1016/j.ensruct.2018.02.073
[2] Gruin A, Baerä C, Enache F, Jurca A Fundamental study for design of hybrid wood laminated glued cross-sections (Hyw-gl) with improved performance under loading International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 18(6.3) pp 219-226 DOI: 10.5593/sgem2018/6.3/S26.029
[3] Tsai M T, Chen P S, Yang T H, Hsu H M, Liu T C 2018 Experimental study on failure mode of reciprocal wooden joint with dowel connection and wooden interlocking WCTE 2018 - World Conference on Timber Engineering
[4] Barbari M, Cavalli A, Fiorineschi L, Monti M, Togni M Innovative connection in wooden trusses. Construction and Building Materials 66 pp 654-663 DOI: 10.1016/j.conbuildmat.2014.06.022
[5] Schilling T J, Allen W L 2013 Design build fender system and panelized construction Ports 2013 Success Through Diversification Proceedings of the 13th Triennial International Conference pp 910-918 DOI: 10.1016/j.conbuildmat.2014.06.022
[6] Wang J, Karsh E, Finch G, Chen M 2016 Field measurement of vertical movement and roof moisture performance of the Wood Innovation and Design Centre WCTE 2016 World Conference on Timber Engineering ISBN: 978-390303900-1
[7] Yttrup P J, Law P W Innovative timber structures National Conference Publication Institution of Engineers (Australia) 91 pp 191-195 ISSN: 03136922
[8] Jarosz M 2014 Insulating timber-framed walls of historical buildings using modern technologies and materials 2014WIT Transactions on the Built Environment 137 pp 491-498 DOI: 10.2495/HPSM140451
[9] Schilling T J, Allen W L 2013 Design build fender system and panelized construction Ports 2013: Success Through Diversification Proceedings of the 13th Triennial International Conference pp 910-918 DOI: 10.1061/97807784413067.094
[10] Buchanan A, Palermo A, Carradine D, Pampin S 2011 Post-tensioned timber frame buildings Structural Engineer 89(17) pp 24-30 ISSN: 14665123
[11] Yttrup P J, Law P W 1991 Innovative timber structures National Conference Publication Institution of Engineers (Australia) 91 16 pp 191-195 ISSN: 03136922
[12] Aleksashkin E N, Veselov V V, Egorov V V 2016 Wooden beam: pat. RU 168412 Russian Federation IPC B04C 3/12 / declarer and patent owner Emperor Alexander I St. Petersburg State Transport University № 2016134585 Appl 23.08.2016 Publ. 02.02.2017 Bul № 4
[13] Aleksashkin E N, Veselov V V, Egorov V V 2017 Wooden beam: pat. RU 2633721 Russian Federation IPC E04C 3/18, E04B 1/26 declarer and patent owner Emperor Alexander I St.
Petersburg State Transport University № 2016134693 Appl. 24.08.2016 Publ. 17.10.2017 Bul

[14] Veselov V V 2017 Wooden beam: патент RU 171490, Russian Federation, IPC 3/12 declarer and patent owner Emperor Alexander I St. Petersburg State Transport University № 2017106069 Appl. 22.02.2017 Publ. 02.06.2017 Бул № 16

[15] Shopski M 2017 Glued-in steel rods subjected to combined axial and lateral loading *Annual of the University of the architecture, civil engineering and geodesy Sofia* **50** 1 2017

[16] Komokhov P G, Maslennikova L L, Makhmud A 2003 Control of strength of ceramic materials by forming the contact zone between clay matrix and leaning agent *Stroitel'nye Materialy* **12** pp 44-46

[17] Maslennikova L L, Abu-Khasan M S, Babak N A 2017 The use of oil-contaminated crushed stone screenings in construction ceramics *Procedia Engineering* **189** pp 59-64 DOI: https://doi.org/10.1016/j.proeng.2017.05.010

[18] Abu-Khasan M, Solovyova V, Solovyov D 2018 High-strength Concrete with new organic mineral complex admixture *MATEC Web of Conferences Proceeding* **193** 03019 DOI: https://doi.org/10.1051/matecconf/201819303019

[19] Bathon L A, Blett C, Schmidt J 2006 Hurricane proof buildings An innovative solution using prefabricated modular wood-concrete-composite elements 9th World Conference on Timber Engineering 2006 WCTE 2 pp 952-959 ISBN: 978-162276285-9

[20] Abu-Khasan M, Egorov V, Rozantseva N, Kuprava L 2018 Load Carrying Wood and Metal Structures of Trusses of Covering of Long Spanned Rail Depot *IOP Conference Series: Materials Science and Engineering* **463(4)** 042075