Prevention of progressive uncontrolled collapse of a high-rise building

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Abstract. This article deals with the problem of security and resistance of the high-rise unique buildings to progressing collapse. The analysis of the causes of accidents and collapses of buildings and structures is carried out. The features of calculations and verification of structures for progressive destruction are explored. The analysis of researches and updating of norms on emergency prevention is carried out. The ways of solving the problems of buildings structural schemes resistance and structures to progressive collapse are shown. Particular attention is paid to the use of outrigger communication floors to improve the level of building survivability. Examples are reviewed from the high-rise buildings construction practice on the territory of the Russian Federation. Recommendations are given for the development of further research and practical application of measures to increase resistance to the progressive collapse of high-rise buildings.

1 Introduction

The volume of high-rise unique buildings construction in Russia abroad increases significantly. This is due to a land shortage with a good urban perspective, price increase, as well as the intention to concentrate administrative buildings in certain financial centers. The desire of large organizations and the state to show their level of scientific and technical progress, the strength and power of the economic condition also affects.

In Russia the active construction of high-rise buildings has recently began, while in the world skyscrapers have been built for more than a hundred years. The extensive experience of erecting "Stalin skyscrapers" on individual projects, which have not been reflected in regulatory developments, is largely lost and forgotten. Nowadays, a major problem in the high-rise unique construction development is the lack of comprehensive all-Russian legal requirements governing high-rise construction. This fact definitely restrains the construction of high-rise buildings throughout Russia.

In Russia, research in the field of buildings progressive collapse has been conducted since 1970. The main scientific centers are: MNIITEP, NIZHB behalf A.A. Gvozdev, Central Research Institute of Housing, the V.A. Kucherenko Central Scientific Research Institute for Building Structures, MSUCE and others.

Studies on progressive destruction are reflected in the works of Almazov V.O., Eremeev P.G., Eremin A.G., Rastorguev B.S., Mrktytchev O.V., Roitman V.M., Perelmuter A.V.

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and other authors.

A significant contribution to the development of research on the prevention of progressive destruction was made by V.O. Almazov, who gave recommendations on the calculation, proposed options for buildings strengthening, investigated the dynamics of progressive collapse, suggested a technique for determining the dynamic coefficient, which depends on the frame height. [1,2,3]

2 Problems and definitions

Ssafety ensuring of buildings and people exploiting them has become a very important topic of high-rise construction. Emergencies at various sites create great economic losses and are accompanied by human casualties. This happens in Russia and in other countries of the world.

Most often, the causes of such accidents and destruction are:

- errors and shortcomings of design solutions;
- poor quality of construction and installation works, technological disruptions in the manufacture of structures;
- use of low-quality building materials;
- non-compliance with the requirements for transportation and storage of building products and materials;
- violation of operating rules;
- imperfection of the regulatory design base;
- local (local) emergency response.

Most often, disastrous situations arise as a result of a set of errors, but, first of all, design engineers 'errors can lead to to the collapse of buildings:

- incorrect accounting of force impacts and loads;
- errors in calculating the spatial stiffness of buildings both during the installation period and during operation;
- applying any changes to the project of the building in the process of construction;
- poor-quality work in joints supporting structure of junction and conjugation.

In construction practice, emergency destruction can occur because of non-qualitative engineering and geological surveys, which lead to key design solutions for buildings and structures.

Sometimes the structures can be damaged as a result of overload of bearing elements, placement of unaccounted equipment in the building, occurrence of vibrations and large dynamic loads during construction and operation.

Particular attention should be paid to the verification of structural calculations for progressive destruction. Required initial condition is a clear understanding of the performance of structures. Paradoxically, however, the excessive interest in computer-aided design sometimes leads to blunders in projects:

- in complex high-altitude structures, physical and geometric non-linearity is not taken into account;
- in reinforced concrete structures the increase in deflections arising from the long-term effect of creep of concrete, and the occurrence of cracks in the case of vibration loading, is not considered.

Quite often, the calculations do not reveal dynamic characteristics, although they can determine the shortcomings of the accepted design schemes.

The development of the theory of progressive collapse and the development of recommendations for the prevention of the high-rise buildings destruction intensified after the loud accidents of buildings abroad, and in Russia. [4]

In 1968 in London, the accident in the building of the residential house showed collapse as an avalanche process. This led to the fact that in the UK in the building code there were requirements for the mandatory consideration of the impact of disproportionate local failures.

In the United States, such recommendations were made in the "set of building regulations" in 1973. Since 1993, the situation has escalated due to terrorist acts: this year there was an explosion of the building of the International Trade Center, in 1995 there was a terrorist attack in the center of Oklahoma City; in 1996 Saudi Arabia underwent a terrorist attack; in 1998 there was an explosion in the American embassies in the cities of Kenya and Tanzania, also there was a terrorist act in the United States on September 11, 2001 in New York, which caused the collapse of the towers of the World Trade Center. After these events, American and European building codes included the requirements for preventing the progressive destruction of buildings and structures. The norms cover the protection of buildings from avalanche collapse; require consideration of a possible terrorist threat and the development of architectural and constructive solutions to limit the destruction consequences. [5]

In fact, calculations for progressive destruction are reduced to the calculation of structures for dynamic short-term loads. In this case, it is necessary to carry out dynamic nonlinear calculations. This task is extremely difficult for practical application. For this reason, dynamic calculations reduce to a corresponding static way of the dynamic factor usage. It shows how much the static load should be increased in order to get dynamic relocation.

To evaluate the building as a whole, the term "survivability" is used in emergencies. It characterizes the ability of the building to resist special influences. Buildings with a high "survivability" should have resistance to progressive collapse, as well as internal and external explosions.

The current recommendations for ensuring sustainability and preventing the progressive collapse of high-rise buildings require the most economical solutions to this problem:

- rational architectural and constructive means, considering a possible emergency situation;
- solutions that ensure the continuity of structures;
- the use of structures and materials that cause plastic deformations in their joints and structural elements

In practice, various methods of resistance to avalanche collapse of structures are applied in high-rise construction [6].

The simplest way is to increase the load-bearing capacity of building elements, its reliability and reduce risk. However, such a decision leads to large economic costs and practically does not exclude the probability of the building losing resistance to a progressive collapse.

The second option is based on increasing the degree of static uncertainty in the building's settlement system. It leads to the localization of the initial damage by the construction and at the same time, there arises the possibility of the forces redistribution that were perceived as the excluded from the system element. This method can lead to an increase in the frequency of setting up the columns (reducing the pitch of the columns), which may contradict the architectural and planning requirements for the design of rooms.

The third approach is to study the likely local destruction of the building, which are analyzed and, on this basis, measures are taken to prevent a progressive collapse. This method is the most acceptable from the point of view of ensuring the safety of the building, taking into account the probability of emergencies.

However, the most economical solution is based on calculated and constructive measures to ensure the building "survivability". Thus, for example, an emergency situation may arise as a result of the destruction of the bearing vertical element - the column. In this case, over the destroyed support without reinforced floors, the overlap becomes involved in the work at the increased span. This changes the sign of the bending moment, leads to considerable deformations, and can change the stress-strain state of the structure.

The device of reinforced bonded floors can effectively work for a monolithic high-rise reinforced concrete frame building in preventing progressive destruction.

The basis of bonded floors, as a rule, are complete outrigger systems, including transverse links from the core to the columns in combination with the bandages (rings). Such floors are usually combined with technical floors. Connections can be made in the form of trusses, frames or slabs. The step of location of bonded floors is determined by the calculation for the progressive collapse, taking into account the location of the engineering systems of high-rise buildings. It is very important to note that outrigger floors not only prevent the progressive collapse of structures, but also increase its ultimate stiffness and resistance to horizontal impacts (wind, earthquake).

Today the classical carrier scheme of a high-rise unique building can be considered as a circuit that includes a core of stiffness, frame columns and outriggers.

An outrigger is a remote element or an external support that connects the core and perimeter columns. The outrigger system is the most effective constructive form of high-rise unique buildings. It includes in the joint work of a hardness core connected to columns, cantilever horizontal links. The linkage system can be made in the form of frames, trusses, beams, slabs or walls that do not work shift. [6, 7, 8]

The core is usually located in the central part of the building, and the outriggers are located on different sides of the stiffness core. This structure increases the lateral rigidity of the structure. At the action of wind, load tensile stresses arise in the columns on the leeward side and in the columns on the opposite side, the compressive stresses.

In conventional outriggers, beams or trusses are directly connected to the core of one side and columns - on the other. In practice, outriggers of a different kind are used, which do not have direct connection of the core to belt bondage (belts). In this case, the work includes interfloor overlapping, as rigid in its diaphragm plane.

In domestic and foreign construction practice, there is a diverse experience in the use of outrigger systems. However, it should be noted that the outrigger design for each building is unique and can differ among themselves even on one object. [9, 10].

To illustrate the operation of the outriggers, it is possible to consider several examples of their application in domestic high-rise construction to increase resistance to the buildings progressive collapse.

Example 1 - the Lakhta Center building in the St. Petersburg.

The building "Lakhta Center" has adopted an outrigger system, which gives it sufficient flexural rigidity. In total, there are five outriggers in the Lakhta Center towers: four two-storied and the fifth is a powerful reinforced-concrete "washer". Outriggers for settlement are located through 14 floors, in the final form the tower can be divided into five separate building blocks. Each 14-storey block is located between two outrigger belts and is a separate engineering and fire compartment.

The project "Lakhta Center" takes into account earthquakes, hurricane winds and all sorts of disasters. Bearing skeleton will save the tower from extreme cases, including the impact of the aircraft, and keep it from the progressive collapse. It is calculated that even with the removal of the third part of the load-bearing elements, the tower will remain stable.

It can be concluded that the 462 meter tower "Lahta Center" is unique in our high-rise construction. On its example, you can check the current standards and work out new ones. In addition, most important – it cannot be allowed to lose the experience of this high-rise unique building construction!

Example 2 - the "Federation" complex in the city of Moscow.

The "Federation" complex is unique in its parameters. It consists of two high-altitude towers: "East" (242 m) and "West" (374 m). The supporting skeleton consists of a monolithic wall central core and 25 perimeter columns. Monolithic overlapping floors unite vertical structures and are horizontal hardness disks. Outrigger floors are made on the height of buildings at different levels. The outrigger floors of the Federation towers are combined with the technical floors in which the engineering equipment and pipelines are located. They provide the required parameters, increase the flexural rigidity of the building, create stability and solve problems of the progressive collapse resistance.

3 Conclusions and recommendations

1. Investigations of various methods of protecting buildings from progressive destruction, allowing significant plastic deformation, confirm the positive effect of outrigger (bonded) floors on load-bearing structures in an emergency.
1.1. Constructions with the use of bonded building floors make it possible to reduce plate deflections and bending moments in slabs in places of local destruction.
1.2. The impact of the emergency response and its consequences in a high-rise building with outrigger communication floors is limited to the block in which the emergency occurred. Having a high stiffness, the communication floor serves as a support for the columns that are outside the blocks with an emergency situation, as well as for columns "suspended" above the area of destruction.
2. The development of research on the progressive avalanche uncontrolled collapse of high-rise buildings shows that in Russia and abroad there are still many problems that set the following tasks:
2.1. It is necessary to develop a system of architectural and constructive solutions that counteract the occurrence of emergencies that lead to the progressive destruction of high-rise buildings;
2.2. Check the calculations of the structural schemes of high-rise buildings, used in practice today, for their resistance to progressive collapse;
2.3. To create a system normative base for high-rise unique construction, including prevention of progressive collapse.
3. To use the international foreign experience of providing high-rise unique buildings resistance to the progressive collapse and the existing domestic experience.

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