On the Question of Protection from Progressive Collapse

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1 Introduction

The problem of protecting buildings and structures from progressive collapse is very relevant all over the world. In recent years, a large number of building collapses caused by emergency impacts, such as household explosions, mechanical removal of supports, have been recorded. The perception of such loads was not previously taken into account in the design. In connection with the increase in such cases and in order to improve the mechanical safety of buildings and ensure the safety of people, in accordance with [1], such loads have become necessary to take into account. Until recently, such loads and impacts, as well as the methodology for accounting for them, did not have the required regulatory framework for calculating them.

To implement this requirement, SP 296.1325800.2017 [1] and SP 385.1325800.2018 [2] were developed.

According to [1], progressive collapse means the successive destruction of load-bearing building structures with the collapse of the entire building or parts of it due to local damage. In an emergency, the destruction of individual load-bearing structural elements is allowed, but these destructions should not lead to a progressive collapse.

On January 6, 2019, SP 385 [2] entered into force, establishing provisions for the design of buildings and structures of normal and increased levels of responsibility of classes KS-2 and KS-3 of various structural systems in order to ensure their protection from progressive collapse.

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2 Research Materials and Methods

The article analyzes the technical literature and scientific research on the issue of progressive collapse, as well as the current regulatory framework.

The design of protection against progressive collapse is carried out in the event of an emergency design situation due to the expected initial local destruction in any place of the building or structure.

Under the assumed initial local destruction (hereinafter referred to as local destruction), it is understood that one load-bearing structural element is excluded from operation, simulating the loss of its load-bearing capacity and (or) stability, which in turn leads to a change in the structural system of a building or structure.

3 Results and Issues

A large number of scientific papers and publications are devoted to the study of progressive collapse [3–12], which indicates that there are many aspects that require attention and further serious study.

When designing structures, scenarios for the implementation of the most dangerous emergency design situations should be developed and strategies should be developed to prevent the progressive collapse of the structure in the event of local structural failure. Each scenario corresponds to a separate special combination of loads and, in accordance with the instructions of SP 20.13330 [13], must include one of the normalized (design) special impacts or one variant of local destruction of load-bearing structures for emergency special impacts.

In [3] calculation of the analysis of the survivability of statically indeterminate reinforced concrete beam and truss structural systems of buildings and structures under accidental impacts, the article formulates the problem of the calculation analysis of the survivability of such structural systems and an algorithm for determining the parameter of vitality, with special effects in the form of sudden shutdown of one of the structures.

Given the authors the analysis of the survivability of excess beam structural systems under accidental impact and the criteria for an emergency limit state for redundant systems allow to define a minimum load level of the structural system (option survivability λ), in which the structural system in case of sudden removal of one bearing structural element (tie) begins destruction, leading to local or progressive destruction of the structure.

The article proposes criteria for the load-bearing capacity at a special limit state of various structural systems that arise under impacts, the excess of which can cause a progressive collapse of the structural system.

As a rule, the strength indicators serve as the criteria for such an assessment [14]. The authors come to the conclusion that structural systems of high-strength materials at small dimensions of the cross-sections of the elements, as well as for structural systems working in harsh environments, when the reduced cross-section or the estimated length as a criterion of resistance to progressive collapse must be considered, and the buckling bearing element of the structural system. The article presents proposals for normalizing the survivability parameters of reinforced concrete structural systems under extreme conditions caused by the sudden loss of stability of the load-bearing element from the accumulation of corrosion damage.

The most common form of protection for operational buildings and structures is the calculation of adaptive adaptability with the imaginary removal of each load-bearing element. In this case, the calculation checks all dangerous variants of local damage. The question arises as to how to perform the calculation, so that when providing protection against progressive collapse, an economically acceptable solution is obtained. To do this, it is necessary to analyze the behavior of the structural system when removing key load-bearing elements.

In the event of a sudden failure of one of the load-bearing elements of the system, there is a need to study the dynamic increase in stresses in the elements of the system. In [5], a definition of the dynamic increase in stresses arising from the reinforcement of two-component composite rod elements during local brittle destruction of concrete is given. When a brittle fracture of the concrete matrix occurs, the stresses acting in the stretched concrete are transferred to the reinforcement. Due to the instantaneous transmission of these stresses, longitudinal vibrations occur in the reinforcing bar, and the magnitude of the dynamic stresses may exceed the calculated tensile strength of the steel.

In [15], constructive proposals for the protection of buildings and structures of an increased level of responsibility from progressive destruction are considered. The authors consider the following active protection methods: the method of creating alternative paths of force resistance, which ensures the preservation of the load-bearing capacity of the structural system after switching off one of the structural elements and the destruction is localized; the method of creating local zones of increased resistance, when the entire building or part of it has increased resistance to beyond-design impacts in the event of accidents; a method of structural synthesis of a constructive system with the creation of predefined requirements.

In the monograph [6] and articles [7, 8], the solution to the problem of ensuring stability to a progressive collapse was obtained in a quasi-static formulation based on the energy principles proposed by Geniev et al. [9]. At the moment, there is no solution to such problems in a dynamic formulation, although this can be a test for approximate solutions to a wide class of practically important problems.

The authors of [16] consider the issues of determining the dynamic characteristics of multi-storey frame buildings with local damage and note that taking into account the time of column removal in a building in comparison with "instantaneous" has a number of specific features that directly affect the value of its natural frequencies, periods, and forms of vibrations. The article presents the results of the calculation of a 45-storey frame building for progressive collapse. The analysis carried out by the authors shows that with the growth of the number of floors, the periods of fluctuations of the building increase, and the frequency of fluctuations decreases. The article considers a building with transition floors, the presence of which reduces the periods of fluctuations due to increased rigidity. The coefficient of dynamism, taking into account the time of failure of the column for such buildings, can be reduced by more than 15%.

It is impossible not to mention the works [17, 18]. In [17], the author notes that the most effective solution to protect buildings and structures from progressive collapse is a probabilistic approach to design. The introduction of such a technique significantly increases the reliability and durability of buildings. The method is based on the method of optimal design of building structures. A deterministic approach to the calculation of building structures leads to overspending of materials due to overstating loads and underestimating the strength characteristics of structures.

SP 385.1325800.2018 [2] sets out the requirements for calculation models. When calculating, a spatial calculation model should be used, which takes into account the interaction with the ground base according to SP 22.13330 [19]. It is necessary to consider the inclusion of items that in normal use are curtains, and when a local destruction of the structures actively involved in the work and participate in the redistribution efforts in the elements of the structural system.

The calculation of structures for stability against progressive collapse should be performed for each of the considered local destructions separately and independently of other possible local destructions.

In the analysis model structures should take into account the real diagram of the material structures and their joints (bundle masonry work under construction on the stretch; non-perception in the platform joint tensile stresses; the brittle fracture of structures and components of their conjugation, etc.) and the possibility of a particular limit state.

To perform calculations, it is necessary to use modern calculation programs that work according to the finite element method. Such programs include SACAD, LIRA-SOFT, LIRA-CAD, and STARKES.

The SCAD software package implements calculation modes for progressive collapse in accordance with SP 385.1325800.2018 [2] and in accordance with section II.6 manuals [20].

According to [20], it is advisable to use the dynamic calculation method when calculating for a progressive collapse, if the object is experiencing technological dynamic effects.

The method of dynamic calculation of extra-centrally compressed reinforced concrete elements in time and the features of calculating buildings and structures for progressive destruction in the entire range of combinations of force and temperature loads are considered in [10, 11].

4 Conclusion

In the course of the study, a review of the literature on the topic of progressive collapse was conducted, during which studies of reinforced concrete structures with a sudden shutdown (removal) of one of the load-bearing structural elements were considered.

It is revealed that as a criterion for assessing the resistance to progressive collapse, in addition to the strength indicators prescribed by the norms, it is necessary to consider the loss of stability of the bearing element of the structural system under dynamic stress increases or other physical influences.

The current regulatory documents do not cover the entire variety of specific situations for buildings and structures that differ in their design features, but contain basic principles of protection against progressive collapse. In order to provide protection against the progressive collapse of buildings and structures with different design solutions, it is advisable to further study this issue in order to specify the provisions of existing regulatory documents, by developing manuals or new sets of rules.

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