Outlook in Making Criteria for Assessing Progressive Collapse of Buildings and Facilities

A I Gabitov1, E A Udalova1, A S Salov1, A R Chernova1

1Ufa State Petroleum Technological University, Mendeleeva St. 195, 450000, Ufa, Russia

E-mail: gabitov.azat@mail.ru

Abstract. Представлен анализ для теоретической и прикладной исследовательской работы по разработке регуляторных и инженерных норм, объединяющих все предыдущий опыт в проектировании, содержании и анализе повреждения инженерных конструкций, учитывая широкий спектр вида воздействий (мертвый, наложенный, динамичный заряды и внешние атмосферные воздействия) на здания и сооружения, и предоставляя безопасное функционирование этого. Термин “последовательное падение” появился в дополнение к основным свойствам несущих строительных конструкций, которые возникли из-за специфических добровольных и окружающих воздействий, которые происходят в исключительных ситуациях, когда местное повреждение приводит к значительным разрушениям, т. е. расширению повреждений на весь объем здания или значительную часть. Проблема защиты от последовательного падения решается в инженерных конструктивных нормах всех развитых стран. Три основных подхода к обеспечению надежности зданий и сооружений: прямой, косвенный и вероятностный. Расчеты всего здания или отдельных элементов в отношении данного аварийного воздействия относятся к прямому подходу. Разнообразные организационные меры, направленные на сокращение риска аварийной ситуации, но не непосредственно связанные с расчетом структуры, считаются косвенным подходом. Вероятностный подход - это оценка риска аварийной ситуации на основе каждого сценария, который должен быть рассчитан. Проблемы сложной системы выживаемости в отношении специфического воздействия должны быть дальнейшим анализом и рассмотрением, при этом большое внимание уделяется нелинейным характеристикам проблем и последовательному падению конструкций, изготовленных из различных материалов.

1. Introduction
Successive destruction of load-bearing engineering structures resulting in failure of the whole building or large parts thereof due to local failure is called the progressive collapse (GOST R 54257-2014. Reliability of building structures and foundations. Basic provisions and requirements. Moscow: Standartinform Publ., 2015). The problem of buildings and structures stability against progressive collapse at beyond design basis emergency failures and local failures is closely connected with the “survivability” concept. The survivability is the ability of the structure to perform satisfactorily if any part thereof is failed [1], or feature of the construction to withstand any impacts without being damaged by disproportionate reasons causing thereof [2]. Emergency destruction of buildings and structures due to various mistakes made both in design and in the course of erecting and maintenance thereof, as well as by virtue of environmental or man-made emergency situations (utility gas explosions, fire, vehicle shocks, terror attacks, etc.) is becoming more frequent in the last years [3, 4].
As was mentioned in [4] amount of accidents is growing year by year, with the whole building or large part thereof and separate assemblies being damaged [6] suggesting thereby that the damages occur due to impacts other than envisaged by the design documentation that the project based on.

The progressive collapse term was initially mentioned in the report of the commission investigating the failure of Ronan Point 22-storey tower block in London in 1968 because of gas explosion in the kitchen on the 18th floor. Origin of the term in addition to main properties of load-bearing building frames, i.e. reliability and safety, is stipulated by special environmental or man-made impacts emerging in extraordinary situations. Not only the explosion and destruction of load-bearing walls and slabs were of interest and concern. This local failure resulted in far most vast destructions. It is the propagation of damage to the whole building or large part thereof that later was named by various experts as progressive collapse, or progressive failure, or explosive rapture as translated from Russian. There appeared an absolutely new direction in design and prediction of construction facilities behavior which is more important. The importance of this direction is that the problem is addressed to for the first time not only from ultimate limit state of the structure but what will happen after this ultimate limit state is passed.

Analysis of this post ultimate limit state is likely to be further studied for safety of buildings and structures to be projected, under construction and operation [7, 8].

2. Analysis of current standards

Emergency impacts at engineering, construction and operation of the construction facilities are to be considered and they are indicated in construction regulations of different countries. One of the first documents regulating constructional safety of building and structures in the USSR according to the analysis of domestic regulations was GOST 27751-88 “Reliability of building structures and foundations. Basic provisions for the calculation”, where it is declared that building and structures are to be engineered so as to be reliable at erection and operation considering special impacts thereon, if any (in particular, as a result of specific man-made and environmental emergency situations – earthquakes, flood, fire, and various explosions).

Version of GOST R 54257-2014 “Reliability of building structures and foundations. Basic provisions and requirements” has made large amendments to the reliability standard. In particular, the design situations as stationary, transitional and emergency ones are sufficiently described. Emergency situation corresponds to exclusive behavior of the structure resulting in significant social, environmental and economic damage [10, 11]. According to GOST “the calculation for progressive collapse if affected by special impact is made for buildings (residential and office high-rise buildings, shopping malls, under-grandstand structures, etc.) of the 1st (1a and 1b) consequence class, unless other procedures excluding the progressive collapse thereof are specified”.

The term “progressive collapse” may be reasonably considered to be mentioned for the first time in domestic literature in the Manual for the design of residential buildings. Issue 3. Construction of residential buildings (SNiP 2.08.01-85). The following recommendations (Recommendations for protecting high-rise buildings from progressive collapse; Recommendations for the protection of residential buildings with load-bearing brick walls in emergency situations; Recommendations for the protection of residential buildings of wall construction systems in emergency situations, Recommendations for the protection of monolithic residential buildings from progressive collapse) may be indicated as the first ones applied in protection of buildings and structures against progressive collapse. It should be indicated that regulatory documents of some countries (ACI 318-14. Building Code requirements for Structural Concrete. American Concrete Institute, 2014; EN1991-1-7-2009. Eurocode 1. Impact on structures. Part 1-7. Special influences. Moscow: Minstrojarkhitektury Publ., 2010) assume probability and potential impacts of the progressive collapse due to accidents. One of definition of this kind of failure is given in ASCE 7-02 Minimum Design Loads for Buildings and Other Structures. (VA: American Society of Civil Engineers, Reston, 2002) as “the spread of an initial local failure from element to element, resulting eventually in the
collapse of an entire structure or a disproportionately large part of it”. Additional precautions should be taken in the design of structures and buildings so as [12] “the structural integrity on the whole remained resistant and undamaged to the degree disproportionate to initial local impact”. Emergency situations that are not considered at conventional design are more likely to become the reasons for destruction. Therewith earthquakes, fire, strong winds that are considered at structural engineering in accordance with current regulations should not result in progressive collapse of buildings.

3. Problems of progressive collapse in world practice
Regulations containing general recommendations to prevent progressive collapse were issued after the Ronan Point accident. Later the similar provisions were issued in the USA [13, 14] and Canada (EN1991-1-7-2009. Eurocode 1. Impact on structures. Part 1-7. Special influences. Moscow: Minstrojarhitektury Publ., 2010).

Tragic events of the last years, in particular two suspended walkways collapse inside atrium of “Hyatt Regency” hotel in Kansas (July, 1981); terror attacks on USA buildings gave rise to new research of buildings and facilities. In 1995 part of federal “Murrah Building” in Oklahoma City was destroyed by an explosion of a mined car which resulted in the first floor column damage with further collapse of load-bearing slabs and beams [15]. Another terror attack took place in New-York in September 11, 2001 in the World Trade Center Towers that were destroyed because of uncontrolled fire [16, 17]. After these events additional reliability measures for protection of nationwide buildings and defense facilities, and, accordingly, engineering and calculation recommendations thereto were issued.

In 2004 water park roof in “Transvaal-Park” (Moscow) was destroyed, in 2006 Basmanny Market roof was collapsed [18, 19]. Then, further damages of apartment building under construction in Taganrog (2012) and barracks in Omsk (2015) resulted in active analysis of the progressive collapse [20].

Conclusions and recommendations under results of simulation and further calculations of structural behavior of multi-storey frames affected by any one emergency load-case are given in [21]. Sudden removal of any one column of load-bearing frame or gas explosion somewhere inside the building under construction may be considered as such load-case. Calculation results of emergency loading by intensity of stress in frame elements, should one of edge, middle or intermedia
to reach places and installation of shielded structures may be considered as examples. Redundancy increase, additional bracing, and arrangement of fixed connections instead of articulated ones are also possible [22].

Direct calculations of the structure on the whole or some elements thereof against the given emergency impact are referred to as the direct approach. If the calculations concern increase of resistance of certain element to emergency impact of the specified intensity it is the “key element” method. Many Russian authors criticize this method due to the fact that reinforcement of certain elements results in increase of material consumption, therewith providing the resistance against just narrow range of emergency impacts.

The second approach under the direct method is removal of one or some elements/bracing from the engineering scheme with analyzing the remaining construction for ability thereof to redistribute extra loads. Principal disadvantage of this approach is subjective attitude to selection of group of elements.
to be removed from the structure. Nevertheless [29] this very approach proved to be more efficient as it enables to get quantitative assessment of internal efforts in the structure and trace the sequence of failures provoked by initial damage. When making the design for special loads without considering physical nature of external action, the behavior of the construction may be assessed, provided the result of this action was local loss of one or more elements thereof. The similar approach is becoming universal when making the design of buildings that may be affected by local failures due to explosions, loss of supports because of karst holes, brittle crushing of overloaded columns, guys break, etc. Essentially, the problem of assessing certain building subjected to the progressive collapse is assessment of stress and strain behavior thereof due to sudden removal of one or several elements and/or bracing.

The probabilistic approach [35] is estimation of emergency situation risk and it is based on statistical data by each scenario to be calculated. A number of the system indicators such as geometrical, strength, strain and external loadings are random values, and the design is aimed at quantitative assessment of the structure reliabilities in the whole course of operation thereof. Therefore, analysis of some provisions, specifications and regulations in design of buildings for the progressive collapse have shown that the problems of complicated system survivability under specific impact thereon are to be further analyzed and considered, therewith more attention is to be paid to nonlinear statement of problems and progressive collapse of structures made of various materials.

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