Assessment of Technogenic Accident Risk of Industrial Building Structures

D A Baiburin¹, A Kh Baiburin²

¹“Structural Safety” LLC, 2, Vitebskaya st., Chelyabinsk 454080, The Russian Federation
²Architectural and Construction Institute, South Ural State University (National Research University), Lenin Ave. 76, Chelyabinsk, 454080, The Russian Federation

E-mail: baiburinak@susu.ru

Abstract. A methodology for assessing the risk of an industrial building accident was developed taking into account the damage caused by various localization of collapse. Before the beginning of the survey of a facility technical condition, groups including the same type of building structures are selected. Further, assessment is made for the reduction in their load-carrying capacity from the strength and stability conditions taking into account defects. The characteristics of the influence of defects and structural damage on a building safety is the degree of compliance with the standards expressed by the reliability level. Reliability levels assignment is carried out on the basis of calculations, operating experience and inspection of a particular type of structure according to the formalized rules. The risk of collapse according to a separate scenario is calculated for structures that are capable and incapable of causing a progressive ossification. The results of the technique application are based on the analysis of the accident risk at the welding shop "Vysota (Height) 239" of the Chelyabinsk Pipe Rolling Plant.

1. Introduction

Calculations of building structures for emergency actions should be part of an integrated system for monitoring the technical condition, based on the analysis and regulation of the accident risk, and also used to justify the safety of a hazardous production facility under Federal Law No. 116-FZ [1]. The magnitude of the accident risk allows to quickly estimate the increase in the probability of an accident with respect to some normal value laid down in construction norms [2-4]. The development of the theory of reliability and security provided a theoretical basis for the solution of this urgent problem [5-11].

In the new version of the Federal Law on Industrial Safety, the status of industrially dangerous objects is removed from some of the construction sites. This means that the objects become uncontrolled by the Rostechnadzor authorities, and the responsibility for choosing the required amount of work affecting safety (inspection, repairs, reconstruction) is actually shifted to the owner. The adopted innovation will undoubtedly negatively affect the safety of buildings and structures due to shortcomings in the mechanisms of technical and legal regulation of structural safety [12-14]. To maintain the proper level of safety of construction sites, it is necessary to develop norms and regulations in the field of safety control and regulation.
The established fact is the conditionality of accidents by gross human errors, approximately 80% of cases [2,3,15]. The sources of errors are insufficient level of professional knowledge, lack of practical experience, lack of information, improper instruction [12,16,17]. Moreover, it is considered that the mistakes made by construction participants cannot have practical consequences if the error is not committed by the person exercising control [15].

For typical designs of civil and industrial buildings, the assumed risk of increasing the probability of failure usually lies in the range 2 ... 10, which is consistent with the data of the studies [2,13,14,17]. The timeframe for the safe operation of defective structures is thereby reduced, and a reduced level of safety may be insufficient in the case of beyond-design impacts related to accidents and emergency situations [12,13,18].

2. Accident risk assessment method

For operating industrial buildings, a methodology is proposed for assessing the risk of an accident, taking into account the damage caused by various localization of the collapse. Before the beginning of the survey of the technical condition of the facility, groups of the same type of building structures are selected. These include the following structures that make up the structural frame of the building: base; foundations; columns; column communications; wall constructions; crane beams; roof trusses and secondary trusses; covering beams; communications over the covering disc; coating.

For each of the groups of similar designs, a detailed examination of the technical condition is carried out, the purpose of which is to identify the most and less damaged structures in the group. Further, an assessment is made of the reduction in their load-carrying capacity from the strength and stability conditions, taking into account defects. Characterization of the effect of defects and structural damage on the safety of the building is the degree of compliance with standards, expressed by the level of reliability. Assignment of reliability levels is carried out on the basis of calculations, operating experience and survey of a specific type of structure according to the formalized rules, depending on the degree of conformity to the project [2-4]. For typical defects and damages, the rules are formulated for the assignment of reliability levels, which serve as guidelines for assessing the technical state of structures. The rules establish the level of reliability depending on the relative magnitude of a defect, deviation.

In addition to analyzing the technical state of structures for calculating the risk of an accident, the estimated damage from failure of each type of structure is estimated. To do this, it is necessary to perform:

- a detailed analysis of the project to determine the sequence of collapse of structures in the event of emergency situations of different locations;
- determining the area of possible damage from the collapse of each individual structure, taking into account the constructive relationships (for example, if the middle column fails, at least two trusses and a part of the cover that rests on these trusses are destroyed);
- an analysis of production technology for the purpose of ranking the areas of the building, depending on the possible damage to technological equipment;
- an analysis and ranking of workshop areas depending on the frequency of people in the operator's, transitional areas, workers and household areas.

During the analysis of the project to determine the sequence of collapse, cause-effect relationships of design failure are identified, and diagrams (diagrams) of the failure sequence are constructed. It is necessary to consider the forward and backward collision sequences, which can be described in the following way:

1) soaking and freezing the foundation soil - foundation sediment - deviation of the column from the vertical - displacement of the center of application of the load to the column - collapse of the column - collapse of the coating truss - collapse of the coating;
2) collapse of the cover - collapse of the truss - collapse of the secondary truss - exceeding the limit load on the secondary truss - reduction of the cross-section of the stem of the secondary truss - corrosion of the secondary truss.
Area of possible damage from collapse of structures $A_d$ is possible to calculate, according to the interbranch rules of the POT RM 0122000 [19]. To the horizontal projection of the maximum dimensions of the construction, the distance of possible departure is added, determined from the table. For areas of possible collapse of walls and columns of half-timbered houses, the area of possible damage is calculated as follows:

$$A_d = (w + d_1 + d_2)(h + d_2)$$

where $w$ – width of wall section, $h$ – wall section height, $d_1, d_2$ – departure distance, respectively, for the bottom and top of the wall, located at heights $h_1$ and $h_2$, determined from the table [19].

For covering, the caving area is calculated as follows:

$$A_d = (w + 2d)(l + 2d) \text{ – for medium spans}$$

$$A_d = (w + d)(l + 2d) \text{ – for extreme spans}$$

where $w, l$ – width and length of the coating; $d$ – departure distance for a section of the cover located at a height $h$.

When carrying out a risk assessment, it is assumed that an assessment of possible damage is based on an analysis of the cost of the equipment and an assessment of the damage from the production downtime with the involvement of relevant specialists. Relative indicator of economic damage from the violation of the technological process:

$$T_i = T_d / T_s$$

where $T_d$ – possible damage to the technological process from caving $A_d$; $T_s$ – possible damage to the technological process from the collapse of the whole building area $A_c$.

When calculating for $T_d$ and $T_s$ it is necessary to take indicators related to the cost of building restoration, equipment, process setup and losses from idle lines.

Calculation of social injury rate, depending on the frequency of people under the zone of collapse:

$$P_d = \sum n_i \cdot t_i / 24$$

where $n_i$ – number of people under the zone of possible collapse; $t_i$ – time of people's being under the zone of possible collapse in a day, in hours; $i$ – number of cases of people in the zone of collapse.

When the whole building collapses, the social damage index is calculated depending on the frequency of people under the collapse zone using the simplified formula:

$$P_s = n \cdot t / 24$$

where $n$ – total number of people in the building; $t$ – time of people's being in the building during the day, in hours.

Relative indicator of social damage:

$$P_i = P_d / P_s$$

To take into account the degree of influence on the magnitude of the risk of an accident of social damage in relation to the damage to the technological process, the social risk ratio calculated in respect of damage from human victims to the damage caused to the technological process in the collapse of the entire building:

$$c_{ps} = P_s \cdot VSL / T_s$$

where $P_s$ – social injury rate; $VSL$ – average life cost; $T_s$ – possible damage to the technological process from the collapse of the whole building.
According to calculations of the average statistical cost of living by the level of specific GDP ($24,805) and average life expectancy (69.8 years), the statistics of insurance payments are recommended to take VSL equal to 2 million rubles [6].

Total relative economic loss:

\[ L_i = T_i + P_i \cdot c_{pl,i} \]  

Calculation of the risk of the accident is proposed to be carried out on local zones of collapsing. Analysis of accidents in industrial buildings allows to determine the unit of the local zone during a collapse - a fragment of the span within the temperature block. Then the risk of an accident is represented by the sum:

\[ R_s = R_{loc,1} + R_{loc,2} + \ldots + R_{loc,i} \]

where \( R_{loc,i} \) – risks of local caving in each separate accident scenario.

When calculating risks, groups of similar structures are divided into two types, depending on the possible consequences: structures capable of causing a progressive collapse of a part of the building or the entire building, and structures that are not capable of causing a progressive collapse of part of the building or the whole building.

The risk of local collapse under a separate scenario for structures incapable of causing a progressive (avalanche) collapse:

\[ R_{loc,i} = L_i \cdot n_{i}^s / \left( n_i^T \cdot n_i^p \cdot P_{mi} \right) \]

where \( n_i \) – number of structures falling into the considered zone of local collapse with the same consequences; \( n_i^s \) and \( n_i^p \) – total number of structures in the zones with the same categories of damage to the technological process and social damage as in the considered zone of local collapse; \( n_i \) – average reliability index for a group of structures, failure of one of which is capable of causing this collapse; \( L_i \) – relative indicator of possible damage to the technological process from the collapse of structures; \( i \) – group number of the same type structures.

The risk of local collapse in a separate scenario for structures capable of causing a progressive (avalanche) collapse:

\[ R_{loc,i} = L_i / P_{mi} \]

where \( P_{mi} \) – product levels of reliability of structures from the sequence of collapse.

3. Example of accident risk calculation

To calculate the accident risk of the workshop "Height 239" of JSC "ChTPZ" it was considered collapse of four types of structures in each temperature block of the building: columns of the extreme row; columns of the middle row; roof trusses; outdoor sandwich panel. The results of calculating the risk in the collapse of structures in the first two temperature blocks are given in Table 1.

The shop under consideration consists of eight temperature blocks. After summarizing the risks of failure of the structures in each temperature block, the overall risk of the building's total accident was calculated, which was 2.42. This means that the level of structural safety of the workshop is sufficient, since the actual risk of an object's accident is in the range of acceptable values. The boundaries of this area are two standard risk values: normal (for new buildings) \( R_n = 2 \) and maximum permissible \( R_{lim} = 19 \) [2]

4. Conclusion

A methodology for assessing the risk of an industrial building accident has been developed, taking into account the damage caused by various localization of the collapse. Based on the results of calculations, a program of maintenance and repair of the workshop can be compiled taking into account the risks of the accident, which will allow implementing a risk-oriented approach to the
operational control and maintenance of the workshop. In accordance with the calculated value of the risk there is the possibility of substantiated insurance in the performance of responsible orders, as well as risk management in the repair and reconstruction of the shop.

Table 1. Results of calculating the risk of an accident in the collapse of the structure of the workshop.

| Block number | Type of caving | \( T_i \) | \( P_i \) | \( P_{di} \), people | \( T_{di} \), ml. rub. | \( c_{pi,i} \) | \( L_i \) | \( R_{loc,i} \) |
|--------------|----------------|-----------|-----------|---------------------|---------------------|----------------|---------|----------------|
| 1            | Middle column  | 0.025     | 0.0094    | 3                   | 525.1               | 0.229          | 0.0271  | 0.0283         |
|              | Marginal column| 0.0119    | 0.0068    | 2                   | 249.24              | 0.321          | 0.0141  | 0.0147         |
|              | Wall panel     | 0.0005    | 0.0448    | 1                   | 9.41                | 4.25           | 0.191   | 6.52 \( \times 10^{-7} \) |
|              | Truss          | 0.0224    | 0.0105    | 5                   | 470.01              | 0.426          | 0.0268  | 0.028          |
| 2            | Middle column  | 0.0229    | 0.0131    | 1                   | 477.31              | 0.419          | 0.0284  | 0.0296         |
|              | Marginal column| 0.0115    | 0.0086    | 3                   | 241.17              | 0.322          | 0.0144  | 0.015          |
|              | Wall panel     | 0.0005    | 0.0448    | 1                   | 9.41                | 4.25           | 0.191   | 6.52 \( \times 10^{-7} \) |
|              | Truss          | 0.0203    | 0.0131    | 4                   | 426.46              | 0.375          | 0.0252  | 0.0263         |

Acknowledgments
The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0011.

References
[1] 2013 Federal law of the Russian Federation 116 of the Federal law on industrial safety of dangerous productive objects (as amended by 04.03.2013 №22-FL)
[2] Melchakov A P, Bayburin D A and Kazakova E A 2013 Structural safety of construction object: evaluation and ensuring (Chelyabinsk: South Ural State University Publ.) p 136
[3] Nikonov N N, Melchakov A P and Rudin V N 2013 About constructions safety Industrial and civic engineering vol 4 pp 29–33
[4] Bayburin D A and Kazakova E A 2011 Accident risk control as a way to ensure structural safety Bulletin of the South Ural State University, series Construction Engineering and Architecture vol 16 pp 4–6
[5] Rzhanitsyn A R 1978 Strength calculation theory of building structures (Moscow: Stroyizdat) p 239
[6] Raizer V D 2010 Theory reliability of structures (Moscow: ABS Publ.) p 384
[7] Bolotin V V 1982 Probability theory and reliability theory methods in the calculations of structures (Moscow: Stroyizdat) p 351
[8] Perel'muter A V 2007 Specific issues of reliability and safety of building structures (Moscow: ABS Publ.) p 256
[9] Smith G N 1986 Probability and Statistics in Civil Engineering (London: Collins) p 244
[10] Lind N 1979 Optimization, cost benefit analysis, specifications Prob. 3rd Int. Conf. on Applications of statistics in Soil and Structural Engineering vol 3 pp 373–384
[11] Spaete G 1987 Die Sicherheit tragender Baukonstruktionen (Berlin: VEB Verlag für Bauwesen)
[12] Makhutov N A, Lobov O I and Eremin K I 2012 Safety of Russia. Safety of construction engineering complex (Moscow: Znaniye Publ.) p 798
[13] Koltaryevskiy V A and Zabegaev A V 2001 Accidents and catastrophes. Prevention and consequence management vol 5 (Moscow: ABS Publ.) p 416
[14] Tamrazyan A G, Bulgakov S N, Rakhman I A and Stepanov A Yu 2012 *Risks reducing in construction engineering due natural and technogenic hazards* (Moscow: ABS Publ.) p 304

[15] Augusti G, Baratta A and Casciati F 1984 *Probabilistic Methods in Structural Engineering* (London: Chapman & Hall)

[16] *Safety assessment of existing buildings and structures 2014* ed K I Eremin (Magnitogorsk: Open company WELD) p 265

[17] Bayburin A Kh 2015 *Ensuring the quality and safety of constructed public buildings* (Moscow: ABS Publ.) p 336

[18] Roytman A G 1987 *Deformation and damage to buildings* (Moscow: Stroyizdat) p 160

[19] 2001 *Cross-sectoral rules for labor protection when working at height POT RM 0122000* (St.-Petersburg: Stroyizdat)

[20] 2011 *Buildings and constructions. Rules of inspection and monitoring of the technical condition GOST 31937-2011* (Moscow: EASC)