

Assessment of reliability and accident risk for industrial buildings

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Abstract. The methodology contains principal provisions on defining reliability and accident risk of industrial buildings and establishes requirements necessary to identify the life expectancy of a building. The methods are intended to be used in diagnostics and identification of the technical condition and life expectancy of buildings that exceeded the lifespan established in their design, reference documentation or after accidents and renovations.

1 Introduction

Today there are a lot of operating industrial buildings whose operating design lifetime expired. Most of these buildings have a metal frame and operate under difficult conditions of manufacturing (high humidity and temperatures, cyclical exposure of the frames, hard and extremely hard working hours of cranes, etc.). The aforementioned factors result in the decommission of construction structures and sometimes even lead to accidents [1]. Timely accident risk and building reliability assessment helps to avoid negative consequences and man-made disasters at manufacturing sites that is one of the main goals in modern construction [2].

2 Methods

A basic concept based on "safe operation depending on technical condition" principle is proposed according to which the reliability and accident risk assessment must be founded on technical condition parameters that provide for its safe and secure operation in compliance with regulatory-technical and (or) engineering (design) documentation with the accident risk assessment based on defining parameters of technical condition [3, 4]. The latter are represented by parameters that when changed (individually or in group) can render the facility nonoperational or get it into the limit state. Logical and probabilistic model of a single-storey building's accidental collapse risk assessment shows that the actual accident risk is a combination of design risk and the risk accumulated during the operating life of a building:

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$$R_{accident} = R_{des} + R_{def} \tag{1}$$

Whereupon R_{des} is the design risk that is estimated (calculated) at the design stage.

R_{def} is an additional accident risk (defect risk) that a building accumulates as a result of its operation and that depends on the number and scale of these defects.

The main provision for accident-free operation is the following relation:

$$R_{accident} < R_{MPL} \text{ or } \frac{R_{accident}}{R_{MPL}} < 1 \tag{2}$$

$$R_{accident} = R_1 * R_2 * \dots * R_n \tag{3}$$

Standard (conventional) calculation model whereupon $R_{1,2,\dots,n}$ is the risk of discovering a critical defect (collapse) of a construction element n of an industrial building.

The calculation of the accidental collapse of an industrial building's frame can be conducted according to the following three possible models:

Model 1. All the construction elements are interconnected and a critical defect in one of them necessarily results in critical defects in all the other constructive elements.

$$R_{accident} = R_1 + R_2 + \dots + R_n \tag{4}$$

Model 2. All the constructive elements are independent and a critical defect in one of them (any of them) will not result in critical defects in all the other constructive elements.

$$R_{accident} = R_1 * R_2 * \dots * R_i + R_3 * R_4 * \dots * R_j + \dots + R_n \tag{5}$$

Model 3. Hybrid model. In case of a hybrid model of interdependent constructive elements of the frame of the combination $R_1 * R_2 * R_3, R_4 * R_5 \dots$ - that is a combination of potential consequences of accidents (intercorrelated events or simply events that influence the sequence of other events). The building accident risk cannot be calculated by summing up the collapse risk of individual constructive elements of a building as its amount will not be objective and will not reflect the real significance of the accident risk. That is why the calculation using the second model must be conducted this way:

$$R_{accident} = (R_1 + R_2 + \dots + R_n) / n \tag{6}$$

In other words this is an arithmetic mean of all the risks of independent construction elements. But it is better to assess the accident risk the following way:

$$R_{accident} = \max \{ R_1; R_2; \dots; R_n \} \tag{7}$$

This means that the accident risk is the maximum accident risk of an individual construction element the critical defects of which do not influence the critical defects of other constructive elements.

The third model accident risk assessment is carried out in similar fashion:

$$R_{accident} = \frac{\frac{R_1 * R_2 * \dots * R_i}{i} + \frac{R_3 * R_4 * \dots * R_j}{j} + \dots + R_n}{n} \tag{8}$$

In other words it is the arithmetic mean of all the risks of independent intercorrelated groups of an industrial building frame's constructive elements.

$$R_{accident} = \max \{ R_1 * R_2 * \dots * R_i; R_3 * R_4 * \dots * R_j; \dots; R_n \} \tag{9}$$

This means that the accident risk is the maximum accident risk of an individual group of construction elements the critical defects of which do not influence the critical defects of other groups of constructive elements.

The collapse model can be presented visually the following way. Variant 1 shows that all constructive elements are interconnected.

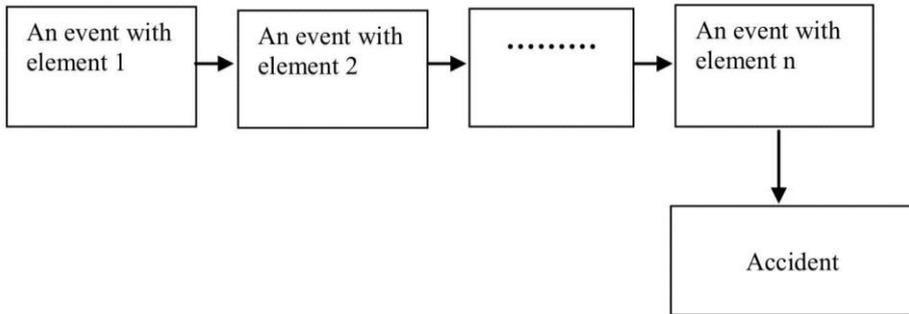


Fig. 1. The model of a potential accident involving an industrial building.

In other words critical defects of any construction element will necessarily result in critical defects in other construction elements and finally in the accident involving the building as a whole.

Variant 2 show that all construction elements are independent.

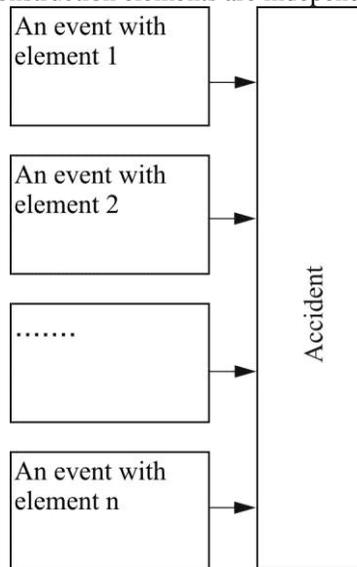


Fig. 2. The model of a potential accident involving an industrial building.

In other words, critical defects of any (one or several) construction elements will not result in critical defects in other construction elements but a critical deviation of any (one or several) constructive elements will necessarily lead to the accident involving the building as a whole.

Variant 3 show the hybrid model.

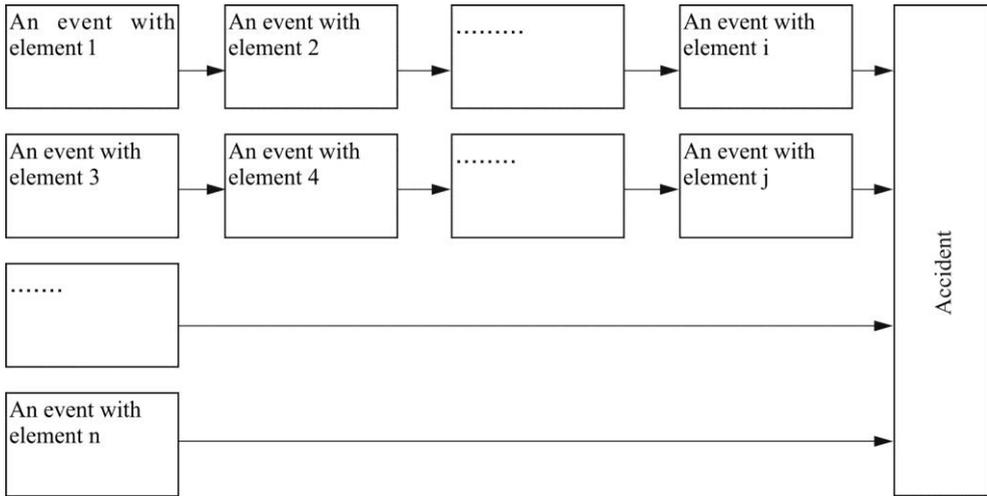


Fig. 3. The model of a potential accident involving an industrial building.

In other words, the critical defect of one group of constructive elements may or may not result in critical defects in other groups of constructive elements (depending on the accident scenario), but in any case these critical defects result in an accident.

The order of multipliers (or summands) depends on the order of events. This said, if in Model 1 the order of multipliers does not matter (as any of the events will cause others to happen), in Model 2 and 3 the first place is taken by the event (among the primary ones) that happened first and resulted in all other events. There can be several primary events. In other words critical defects can be discovered in several places at once (the bottleneck) and lead to a number of certain events.

Thus a question of the difference in the effect of various events on the following events emerges despite the same importance class of constructive elements.

The importance class of constructive elements is the amount of the influence a constructive element exercise among other constructive elements on the overall endurance of a building. (The first class is the one most prone to critical defects. The second is less prone. The third is almost not prone at all).

The primary risk is the risk of the first manifestation of a danger that shows in exceeding the permitted defect values of the first importance class constructive element *i* (or a group of construction elements *ij* of the first importance class) up to the critical level where the constructive element (a group of construction elements) is destroyed with the ensuing chain reaction affecting construction elements with the same importance class or lower.

In order to assess the accident risk it is also necessary to use either the arithmetic average:

$$R_{\text{accident}} = \frac{\sum_{i=1}^n R_i}{n} \tag{10}$$

or choose the maximum accident risk possible but you would have to work with the original formula:

$$R_{accid} = \max\{ R_1; R_2; \dots R_n; R_1 * R_2; R_1 * R_3; R_1 * R_i; \dots; R_2 * R_i; R_1 * R_2 * \dots R_i \} \quad (11)$$

Practical implementation of accident risk assessment methods in case of metal frames of single-storey industrial buildings that operate in iron-and-steel industry is an equally crucial issue. Statistics show that approximately 80% of construction accidents involving collapsing supporting structures happen as a result of man-made errors in design, construction and operation of buildings. These errors constitute the internal (objective) accident risk that influence both the lifetime (an object's resources) and the amount of damage in case of an accident [5, 6].

Accident risk assessment of buildings is conducted on the basis of primary data collected by experts. The data is amassed at all stages of an industrial building's lifetime from design to operation. The data collection must be conducted at least once in a year. The more data one has, the more accurate is the accident risk assessment [7].

It is essential to identify Importance Class 1 on the basis of the groups of a building's elements that define the class and to continue the work in accordance with this class of constructive elements.

Then a model of how constructive elements influence the overall condition of a building (an event tree) is produced. We have already described in this article three models of events: with absolutely dependent elements, with wholly independent elements and a hybrid model with both dependent and independent constructive elements. As a rule, the independent model is very rare. This is why the calculation will be conducted based on the first and third models. The accident risk of a building will be equal to the primary accident risk of a constructive element (a group of constructive elements) of the first class of importance with the gravest critical defects or with higher (or exceeding) risk levels.

The safety of supporting structures depends on the level of zero defects that is calculated by the formula which requires permissible and maximum values for the parameters in question.

$$P_{structures} = \exp \left[\frac{-(x - y)^2}{(tu)^2} \right] \quad (12)$$

whereupon

x is the changed value of the controlled parameter's property;

y is the value of the variable x defined in accordance with the requirements of a project;

u is the limit value of the variable x;

t is a number that characterizes the effect of a parameter on safety levels

It is necessary to take into account the peculiarities of the technological process while assessing the accident risk of supporting structures. In iron-and-steel industry it is the level of active factors of inner environment and technical mechanisms, such as [8]:

- high temperature (more than 115⁰C);
- melted metal;
- the presence (use) of oxygen (23-100%);
- the presence (use) of a combustion gas;
- the presence (use) of an inert gas;
- internal pressure (more than 0,07 MPa);
- release of exhaust gases (with a potential of forming an explosive mix);
- presence (use) of alcali and acids in the technological process;
- combustible liquids, alcali and acids in storage;
- a cooling system (with potential contact between the cooling liquid and melted metal);
- combustible liquids used in the technological process;

- high mechanical velocity (more than 1 meter per second);
- mechanical danger: moving machines and mechanisms, various transport and hoisting devices and transported cargo, unprotected moving parts of industrial equipment (power-driven transmission gear, cutting instruments and devices, rotating and moving devices), parts coming off processed materials and instruments;
- electric danger;
- combustible materials.

The level of active factors of internal environments and technical devices is calculated using the following formula:

$$L = \frac{\sum_{i=1}^f X_i}{f} \times Z_1 \times Z_2 \quad (13)$$

whereupon X_i is a score evaluation of the level of active factors in the internal environment and technical devices. -

$$\left\{ \begin{array}{l} X_i = \frac{\text{actual_value_of_a_parameter}}{\text{permissible_value_of_a_parameter}} \end{array} \right. \quad (14)$$

with $x_i \geq 1$

A permissible value of the parameter stated at the building's design stage is used as a denominator. In case the actual value of the parameter is lower than it is permissible, x_i becomes 1. In case there is no acceptable value, x_i becomes 1,1.

Also in case the calculation of x_i is difficult due to limited estimated data, the expert method of appointing x_i is used, whereby the following principle is applied: $x_i = 1$ - the level of active factors of the internal environment and technical devices does not exceed the norm; $x_i = 1,25$ - the level of active factors of the internal environment and technical devices exceeds the norm but inconsiderably; $x_i = 1,5$ - the level of active factors of the internal environment and technical devices considerably exceeds the norm.

Z_1 is the coefficient that takes into account the operating life of all the technological equipment

$$Z_1 = 1 + \frac{T_{act}}{T_{nom}} \quad (15)$$

T_{act} is the actual lifetime of technical devices in the building in question, in years;

T_{stand} is the average lifetime according to the specification (standard) or other regulatory documents, in years; In case the equipment does not have a specified lifetime $Z_1 = 1$.

Z_2 is the coefficient used based on the results of the expert evaluation of the technical condition of equipment.

f is the number of active factors of the internal environment and technical devices (16 factors are suggested for iron-and-steel industry).

So, this is the basic correlation that shows the probable accident-free operation of a building: the risk of accident should not exceed the maximum permissible level ($R_{accipuu} < R_{IIIV}$).

The accident risk ($R_{accident}$) will also depend on the reliability of structures in the building that in its turn is affected by the reliability of supporting structures of the frame and technical devices (P_{struct}, L).

As a whole, depending on the model, the accident risk accumulated during the operation will equal:

$$R_{\text{accident}} = L \times R(p_{\text{structure}}) \quad (16)$$

$R(p_{\text{structure}})$ is the accident risk of supporting structures for single-storey industrial building.

L is the coefficient that shows the level of active factors of the internal environment and technical devices.

This said, the reliability level of construction structures $P_{\text{structure}}$ also depends on the accident model shown above.

With the graphic model 1 (dependent):

$$R(p_{\text{structure}}) = 1 - (P_1 * P_2 * \dots * P_n) \quad (17)$$

With the graphic model 2 (independent):

$$R(p_{\text{structure}}) = 1 - (P_1 + P_2 + \dots + P_n) \quad (18)$$

With the graphic model 3 (hybrid):

$$R(p_{\text{structure}}) = 1 - (P_{1j} * P_{2j} * \dots * P_{nj} + P_{1k} * P_{2k} * \dots * P_{nk} + \dots P_{jk-1} * P_{nk}) \quad (19)$$

3 Conclusions

Reliability levels of constructive elements (P) are calculated depending on the defect level of the construction element in question, the rate of the constructive element in question and the age of the object of the research (industrial safety assessment).

Depending on the calculated accident risk and after comparing it to the maximum permissible level, one of the decisions is made: to extend the operation lifetime based on the specified parameters, to limit the parameters of technical operation, to assess the remaining lifetime or to decommission the building in question.

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