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Algorithm for modeling possible failures at the construction site

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This article presents the main prerequisites for the development of an algorithm for modeling the possible accident occurrence at the construction site. The paper presents statistical information of the buildings and structures accidents for 2000-2022. The article proposes an algorithm for modeling the possible accident occurrence for use in design documentation in construction. The modelling algorithm is presented in the form of a block diagram, the main provisions for its implementation are described. The developed algorithm is based on the results of statistical processing of information on buildings and structures accidents and can be performed by design engineers on the basis of visual three-dimensional model of the designed building

Keywords: statistics, modeling, accident, building, probability of an accident, destruction, consequences, systematization.

Алгоритм моделювання можливих відмов на будівельному об'єкті

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В даній роботі проедставлені передумови та основні завдання у розробленні алгоритму можливого виникнення аварії на будівельному об'єкті, сформульовані мета дослідження, його актуальність, опрацьовані наукові джерела попередників та виділено наукову новизну. Робота аргументує створення даного алгоритму та розгорнуто представляє на чому саме він базується. Перша частина роботи присвячена передумовам до створення алгоритму, а саме статистиці аварій будівель та споруд за 2000-2022 роки. Виокремлено основні етапи класифікації аварій, звернута увага на методику розроблення бази даних аварій будівель та споруд. Представлені основні результати аналізу статистичної інформації аварій будівель та споруд. В статті запропонований розроблений алгоритм моделювання можливого виникнення аварії до використання у проектній документації у будівництві. Друга частина статті присвячена основним положенням розробленого алгоритму можливого виникнення аварії будівлі або споруди. Розроблений алгоритм базується на проведеному аналізі аварій будівель та споруд, в результаті якого було можливо визначити найбільш необхідні до впровадження сценарії моделювання можливого виникнення аварії. Робота описує сутність та мету даного алгоритму, етапи виконання та детальний опис кожного сценарію моделювання. У статті представлено класифікацію етапів впровадження алгоритму за рівнями значущості та розглянуті їх можливі сценарії в залежності від типу будівлі що проектується. Також у статті представлені основні розрахункові тезиси із детальним описом виконання моделювання сценарію аварії. Даний алгоритм реалізується на обємній моделі будівлі інженерами-проектувальниками на етапі виокнання проектної документації із метою забезпечення надійності та безвідмовності юудівельного каркасу. Основні критерії оцінування деформованої моделі та рекомендації щодо її аналізу представлені у висновках даної роботи.

Keywords: статистика, моделювання, аварія, будівля, імовірність аварії, руйнування, наслідки, систематизація.

Introduction

At the present stage of the construction industry development, the issue of reliability in construction is an important and integral part. A large amount of scientific work shows interest in this area of research, and the continued accidents occurrence in construction confirms its relevance and necessity. The concepts of reliability and scientific research in this field have become the basis for considering the building accident possibility in the theoretical component. Thus, scientific facilities are launched to conduct the calculation of the accident possibility. The concepts of accident economic and non-economic consequences, survivability indicators of building structures, the structural failure probability, reliability indicators, coefficients of working conditions, etc. With the experience gained in the design and construction of humanity, there are opportunities to collect, systematize and eliminate accidents in construction. All the above factors are the main theses in the need for research on accident modeling at the design stage of the construction site.

Review of the research sources and publications

The basics for creating an algorithm involve the study of a wide range of materials. Speaking about statistical data, the fundamental works of the last century were worked out by such scientists as Sakhnovsky M.M. [1].

For instance, the results of processing statistical information on accidents in China for 2009-2019, which are presented in the work of scientists Fangyu Chen and Yongchang Wei [2] and others, are very exhaustive. Questions of reliability, risks, as well as the development of a quantitative assessment of uncertainty in engineering represented by a number of scientists, such as Raiser V.D. [3], Pichugin S.F. [4], Semko O.V. [5], Milchers R.E. [6].

Definition of unsolved aspects of the problem

In recent years, the scientific activity on reliability in construction has clearly formulated the main directions for the further scientific development of this issue. Thus, it is possible to present a reasonable list of tasks in the solution of which there is a need nowadays, namely:

1. Accounting and systematization of buildings and structures accidents occurring in Ukraine and abroad, with the need for constant improvement of the database in order to maintain its relevance.
2. Analysis of the accident causes and consequences, their classification according to the type of accident occurrence, according to the type of its probability (predictability), according to the severity, damage level, as well as the type of construction object.
3. Study and modeling of accident scenarios and mechanisms of a building frame destruction, as well as elements and nodes of their connection.
4. Investigation of the occurrence causes and statistical analysis of the defects accumulation in buildings and structures, their classification as the destruction initiators. Accounting for the influence of the time factor on the damage intensity to structures and the change (deterioration) in the building materials properties.
5. The study of the real (actual) frame operation and the operating conditions' features of the supporting structures of various types and purposes of building objects. At the same time, it is advisable to include related work with bases and foundations, work with process equipment, as well as with buildings and structures located near the object.
6. Technologies and methods creating for modeling accidents are presented in the classification table. Kinematics study of the building structures' stress-strain state, monitoring the destruction level of structures and studying the progressive failure probability.
7. Technological background and methods creating for modeling the possible accident occurrence at a construction site by design engineers at the stage of developing the project documentation. The result of such work can be an algorithm, an example of which is presented in this article.

These issues are currently of high interest to scientists in the construction industry and are considered promising for further scientific research. It should also be noted the practical significance of the goals set, which can be further used in the project design documentation.

Problem statement

The purpose of the work is to create a methodologically and theoretically substantiated algorithm for modeling the accident probability at a construction site for the possibility of further implementation in state building codes. This algorithm aims to resolve issues of inconsistency in the study of ensuring the building frame reliability at the design stage. This algorithm is recommended to be used by design engineers and presented in the project documentation.

Basic material and results.

<u>*1. Statistics of accidents in buildings and structures*</u>

1.1. Collection and analysis of accidents in the construction

An extended information space made it possible to create an information table regarding accidents of buildings and structures of various types. During the study of statistical information about building accidents over the past century, the main theses of the work were identified, namely:

– *Statistical accidents collection is carried out according to the 21st century.*

– *Mandatory data for creating accident statistics are* the date, place of occurrence, information about destruction, building type, a number of stories, frame structure, consequences of destruction (economic and non-economic losses), and causes of destruction (if possible to determine).

– *Statistics of accidents have no territorial restrictions* and include all cases of buildings and structures destruction in any country.

– *Accident statistics do not include massive natural disasters* that caused the simultaneous destruction of more than three buildings.

– *Accident statistics do not include the buildings' destruction due to full-scale hostilities.* But considers isolated cases of terrorist acts and accidental explosions.

– *Accident statistics include cases of fires* at a construction site as one of the factors in the possible progressive destruction occurrence.

The stages of analytical data processing included the information collected in a unified table. The collected and processed material was classified similarly to the structures work graph [7], namely, accidents during construction and acceptance in operation, during operation, and due to big age (reconstruction, technical inspection) [8, 9]. Each classifier is supplemented with subclasses specifying the cause of the accident.

1.2. Statistical results of buildings and structures accident analysis

Based on the graphical analysis, it was found that the largest accidents percentage occurs at the stage of design and acceptance in operation (54%), for multi-story residential buildings (55%), usually as a result of non-compliance with construction norms (50%) include violations of safety rules, design errors, illegal construction and use of poor-quality materials [10].

Based on the statistical analysis, the accident probability was calculated.

2. Algorithm for modeling the possible accident occurrence at a construction site

2.1. Algorithm basics

– The algorithm for modeling the possible accident occurrence at a construction site is used by engineers at the stage of development of design documentation for the construction site.

– To perform the algorithm, it is necessary to use three-dimensional visualization of the designed building using a software package that meets the project requirements.

– The algorithm is not the calculation and design construction stage, but is the basis for making changes to the existing project in case of need, or recalculation and redesign to eliminate errors at the design stage.

– The algorithm is not a requirement to perform but only serves as a tool for additional construction control at the design stage of the construction site.

–The buildings included in this algorithm advicely should be supplemented based on the practice of modern construction in Ukraine (special design solutions, materials, construction systems, etc.).

– *The purpose of the algorithm* is to study the progressive collapse possibility at the construction site, identify the most vulnerable project areas, and general verification, which avoids mechanical errors in the calculations. The result of the revision is the engineer's conclusions based on the visualization of the building structure accident simulation**.**

– Based on the analysis, you can make changes to the project if necessary. After that, the condition of rechecking for individual points of the algorithm is mandatory.

– The created algorithm allows to carry out a complete building analysis and also takes into account the building significance level and frame complexity, thus highlighting the main priority stages. Such a system allows engineers to work out only the necessary destruction models, without considering the minor structure failures.

2.2. Algorithm execution methodology

The sequence structure of the algorithm implementation includes:

1. Depending on the building type, a class of consequences is chosen [11].

2. Determination of significance levels. The consequences class is the main criterion in the gradation of the modeling priority.

This gradation is called the significance level of the stage. In total, three levels (stages) of analysis are planned for implementation.

Level one - meets the basic requirements that are mandatory for any engineering project, of different complexity types, consequences, and significance classes. The first level is basic and should be presented in the design documentation of a civil or industrial building.

Level two is the next modeling stage of the possible accident occurrence at a construction site. Complies with the requirements that must be met for buildings with a consequences class CC2.

Level three - after the visualization and processing of the destruction findings in stages 1 and 2, it is necessary to carry out the following analysis for buildings with a consequences class CC3.

For each type of building, information is provided regarding the level (stage) of the analysis. In this way, the engineer can run the algorithm modeling in order from the most important to the least significant possible accident occurrence.

Analysis and conclusions on the deformation frame model.

Based on the deformation model analysis of the calculated frame with the fulfillment of the modeling condition for each variant of the possible accident occurrence at a construction site, the following conclusions can be presented:

– If obvious errors are found in the design, they must be eliminated.

– If obvious dangerous sections of a construction site are found during its further operation, it is necessary to take precautionary measures in order to reduce the level of such site danger.

– In the event of avalanche-like destruction in one or more variants of modeling the possible accident occurrence, it is necessary to strengthen the building frame or install additional ties.

– Studying the mplementation of the individual projects i, depending on the individual approach to modeling, it is necessary to identify individual hazards and submit them to the project documentation with the materials of the general accident modeling analysis.

2.3. Basic calculation theses. Description of modeling

2.3.1. Estimated errors (roof designs)

1. Checking the framework by obtaining a deformed model. Modeling of excessive snow loads, loading of a roof design in three stages for two types of loadings $Q_1 = 1{,}05Q_0$; $Q_2 = 1{,}2Q_0$, where Q_0 - snow loads are calculated according to the project.

2. Checking the nodal joints work of roof structures. Specification of horizontal and vertical loads on nodes with value $Q_1 = 1{,}2Q_2$.

3. Checking the destruction sequence, in order to eliminate the progressive destruction of the frame. Removal, or formation of a rupture of a key overlapping element at the point of the greatest moment occurrence (it is defined by calculation), when applying the forces designed according to building standards and regulations. In case avalanche-like destruction formation with the transition to the destruction of vertical bearing designs of a framework, it is necessary to carry out strengthening of the existing roof structures.

Checking the probability of snow bag occurrence. In places of possible snow bags occurrence to overload the overlapping $Q_1 = 1.5Q_2$.

2.3.2. Estimated errors (load-bearing frame structures)

1. Checking work of the load-bearing and enclosing structures or other frame structures. Modeling of calculated vertical loads on load-bearing structures of the frame.

2. The frame element should be selected considering the most dangerous area at the facility (including the place of maximum stay of people, the location of large-sized, difficult-to-build production facilities that can create additional critical loads, including vibrational, on structures, or areas where structures are most exposed to aggressive environments).

3. If significant deformations are detected in stage 1, it is necessary to simulate the destruction of the structure as a result of its deformation by overloading it with extra forces, or, in order to study the probability of progressive destruction of the frame - its complete removal.

2.3.3. Use of inappropriate material

Prerequisites for the implementation of such accident possibility modeling stage is a high percentage of multi-story residential buildings destruction as a result of builders' mistakes in mixing mortars, purchase of material that does not meet building standards or use of material with strength characteristics below design in order to save money.

When modeling the possible accident's occurrence in a result of mistakes presented above, the structures' operation is checked in case of the possible use of low-quality material, or its savings by changing the structure material strength in the specified values at the stage of frame designing. Analysis of the deformed model as a result of changes.

1. Reducing the bearing capacity of one load-bearing element of the frame by reducing its design resistance f by one strength class, at the initial stress level $\sigma/f \leq 1$. Then, it is nessesary to provide an analysis of the deformed model.

Taking into account the decrease in material strength f_{er} in the event of errors listed at the beginning of this paragraph, the strength is multiplied by the coefficient of decrease

$$f_{er} = kf_{mat} \ ,$$

where k – the coefficient of material strength reduction depending on the errors.

Conditions for modeling the possible use of low-quality material on the construction site are

$$k = 1 - \sum\left(P(R_{1.1}) + P\left(R_{1.3}\right)\right) \leq 1 \ ,$$

where $R_{1.1}$ – possible builders mistakes;
$R_{1.3}$ – the possibility of using low-quality material.

If $k = 1$ the condition of using the appropriate material on the construction site is accepted.

To determine the accident probability of the $R_{1.1}$ and $R_{1.3}$ types in the building destruction as a result of non-compliance with standards and technologies, we use the Bayesian formula

$$P(R) = P(R_{1.1}*/R_{1.1})P(R_{1.1}) + P(R_{1.3}*/R_{1.3})P(R_{1.3}) \ ,$$

where $R_{1.1}*$ and $R_{1.3}*$ - conditions of no this type accident.

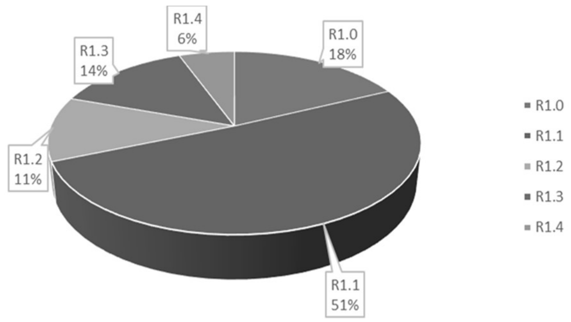

Figure 1 – Diagram of the percentage of the accidents in construction as a result of non-compliance with building codes and technologies for 2000-2022

Probability of accident (provided that the accident occurs in any case) as a result of builders errors $P(R_{1.1})$=0.785, and due to the use of inappropriate material $P(R_{1.3})$=0.215 (according to the statistical data in Fig. 1).

2. Changing the stiffness of several load-bearing elements of the frame on one construction site section $E = 0{,}8E_0$, where E_0 is the initial stiffness of the structural material. Analysis of the deformed model.

3. The total change in the stiffness of the whole structural scheme, where $E_1 = 0{,}9E_0$, where E_0 is the initial stiffness of the material structure. Analysis of the deformed model.

In the event of possible progressive destruction or the individual elements destruction, it is advisable to strengthen the structures in order to eliminate such accidents possibility.

When modeling an accident of this type, it should be paid attention to the area of construction and the state of economic stability in which the construction is carried out. Thus, for countries with a higher possibility of accidents occurring (India, Egypt), this stage of modeling is mandatory.

2.3.4. Building codes violation, deviations from the project

Checking the framework with the replacement in a statically indeterminate system of bracing types (mostly overlapping structures). Analysis of the deformed model.

2.3.5. Destruction of load-bearing structures due to improper operation (overloads on the overlap of the upper spans)

Checking the framework by obtaining a deformed model. Modeling of overloads on the attic floor structure, or (in its absence) on the roof structure (storage of building materials, such as bricks, in large quantities). Setting the live loads on the floor in two ways: evenly distributed with the value $q_1=1,5q_0$ and concentrated forces *F* (located on the frame nodes and in the middle of each floor span). Analysis of the deformed model.

2.3.6. Destruction of load-bearing structures due to improper operation (excessive vibration loads in the nodes of the upper frame spans)

Checking the framework by obtaining a deformed model. Modeling of overloads on the attic floor structure, or (in its absence) on the roof structure (installation of air conditioners or any equipment that during operation creates additional vibration loads on the structure.). Setting the load on the floor, temporary vibration loads in the form of concentrated forces F, located on the frame nodes and in the middle of each floor span. Analysis of the deformed model.

2.3.7. Probable occurrence of an explosion

Checking the overall frame strength of a building in the event of a sudden explosion (for example, storage of explosive materials, terrorist attack etc.).

2.3.8. Untimely repair and incorrect reconstruction

Checking the ability of floor structures to withstand excessive sudden loads due to the destruction of the upper floors of the building. Simulation of the destruction of the upper floor with the overlapping removal from the frame of the structure O_1, loading the previous span O_2 with additional temporary loads equal to the load Q_1 from the removed overlapping. Analysis of the deformation model.

In the event of avalanche-like frame destruction, measures should be taken to strengthen the structures or provide the project with additional means to eliminate progressive destruction.

With significant deformations of the frame, but without obvious avalanche destruction, it is advisable in modeling to remove the overlapping O_2 and load the subsequent floor of the lower tier O_3 with additional loads on the structure equal to $Q_1 + Q_2$.

2.3.9. Untimely or incorrect dismantling of frame structures

Presenting possible options for dismantling the building in case of needs. Note the special moments of individual structures' work.

2.3.10. Special accidents depending on frame structures

In this part of the algorithm, it is expedient to give an example of a light steel framing design.

Modeling of excessive snow loads, loading of a roof structure in three stages for two types of loadings $Q_1 = 1,05Q_0$; $Q_2 = 1,2\ Q_0$, where Q_0 - snow loads are calculated according to the project.

Checking the framework by obtaining a deformed model, checking the possibility of snow bags, checking the sequence of destruction, eliminating the progressive destruction of the frame, if necessary, strengthening the roof structures, or its replacement.

An individual approach is used for this framework in determining the priority (significance) of the modeling stages.

2.3.11. Special accidents depending on the construction area

It is necessary to take into account the peculiarities of the construction area during the possible accident occurrence modeling. Thus, the list of accident modeling includes areas with excessive rainfall, seismically dangerous areas, as well as mountainous areas or slopes.

For areas with excessive precipitation is conducted checking the framework in case of significant flooding of foundations and their subsequent destruction in order to investigate the possible occurrence of progressive destruction.

Carrying out modeling of the building frame accident by removing the extreme row foundation structure from work. Analysis of the deformation model. In the event of avalanche-like destruction of the entire frame, stability should be ensured by reinforcing structures or additional ties.

For seismic areas is conducted checking the framework in the event of oscillating loads on the base of the frame in order to investigate the possible occurrence of progressive failure. The simulation is performed by setting additional loads on the supports, considering seismic oscillations. Analysis of the framework, determining the values of loads that can withstand the avalanche-like destruction of the building.

For mountainous areas, or slopes is carried out the investigation of the course of building frame destruction as a result of landslides, by changing the geometry of the frame (changing the foundations' position). According to the project, two options of shear are chosen: shear of the extreme support (or depending on the building frame - sections of 1×1 m) and failure of the foundations in the center (support, or section of 1×1 m). In the event of an avalanche collapsing, possible frame reinforcement or the fixing of additional bracings should be considered.

Conclusions

During the study, more than 200 accidents that occurred during the period 2000-2022 were processed. According to the results of the created buildings and structures accidents database, their classification and statistical analysis of the received information were carried out. The prerequisites for the algorithm creation are the key aspects of standardization of probabilistic reliability calculations and predicting possible emergency situations, with the possibility of compiling an accident development scenario according to current building codes.

The scientific work results are the creation of an algorithm for modeling the possible accident occurrence at a construction site. The algorithm has been development to be implemented in stages by design engineers based on a three-dimensional building model. Based on the accidents' classification, the algorithm structure has been developed, with a detailed explanation of the possible failures and/or destruction steps modeling by types of accidents and buildings.

The algorithm presented in the paper can be used to simulate the possible occurrence of accidents of various types. Based on this the final conclusions about the designed construction site reliability and the progressive destruction probability can be established.

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