

**NATIONAL UNIVERSITY OF CIVIL
DEFENCE OF UKRAINE**

THE INTERNATIONAL CONFERENCE “PROBLEMS OF EMERGENCY SITUATIONS” (PES 2025)

**SELECTED PEER-REVIEWED FULL TEXT PAPERS FROM THE
INTERNATIONAL SCIENTIFIC APPLIED CONFERENCE
“PROBLEMS OF EMERGENCY SITUATIONS”
(PES 2025)**

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**National University of Civil
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**The International Conference
"Problems of Emergency
Situations" (PES 2025)**

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May 14, 2025, Kharkiv, Ukraine

Edited by

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Trans Tech Publications Ltd
Seestrasse 24c
CH-8806 Baech
Switzerland
<https://www.scientific.net>

Volume 170 of
Advances in Science and Technology
ISSN print 1662-8969
ISSN web 1662-0356

Full text available online at <https://www.scientific.net>

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Trans Tech Publications Ltd
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Evaluation of Fire-Damaged Concrete Structures Using the Non-Destructive Testing

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Keywords: non-destructive testing, structural integrity, concrete strength, Schmidt hammer method.

Abstract. This study analyzes the impact of high temperatures on the physico-chemical properties of concrete, highlighting a marked decrease in strength and material integrity. Among the mechanical non-destructive testing methods, the rebound hammer technique was selected for its accessibility, speed, and capacity to deliver preliminary on-site results. Field data obtained at fire-damaged sites reflect the extent of material degradation and enable the identification of critical heat-affected zones and potential fire origin points. By comparing the strength of concrete in damaged versus intact areas, the most severely affected zones can be identified.

1 Introduction

In the context of martial law caused by the large-scale armed aggression against Ukraine, a significant number of buildings and structures – including residential, public, and industrial facilities – have sustained damage as a result of hostilities [1]. One of the most common types of damage is fire, which can occur either as a direct consequence of ammunition strikes or due to secondary factors such as short circuits, explosions, or the disruption of life-support systems [2, 3].

The lack of systematic recommendations for the use of non-destructive testing methods for assessing fire damage to structures complicates their practical implementation, especially in conditions of hostilities or shelling in the rear. Modern fires are often accompanied by explosions, which creates combined thermal and mechanical loads on buildings. As shown in [1], explosions significantly increase the total load on structural elements, increasing their damage. At the same time, [2] substantiate the effectiveness of easily removable structures to reduce explosive pressure. This confirms the need for a comprehensive approach to assessing the technical condition of structures during a fire and subsequent fires with explosions.

Following a fire, structural elements – particularly those made of reinforced concrete – may suffer hidden (internal) damage that is not always detectable through visual inspection [4]. Under conditions of limited resources and the urgent need to make rapid decisions regarding the suitability of buildings for continued use or restoration, the application of non-destructive testing (NDT) methods becomes critically important. These methods enable efficient, accurate, and non-invasive assessment of structural degradation.

Various approaches to the classification of fires by their source can be found in the scientific literature. In particular, reference divides fires into two main groups based on their place of origin:

- fires in open spaces, such as forest and steppe fires;
- fires in enclosures, which occur and develop inside buildings and structures.

In addition, fires are classified according to the type of combustible material involved: combustion of solid combustible materials and substances; combustion of liquid substances; combustion of gaseous substances; combustion of metals; and combustion of electrical installations under voltage.

It has been established that the fire resistance limit of structures can vary significantly depending on the applied temperature regime, highlighting the need to consider real fire scenarios when

designing and assessing building safety [4]. Reference [5] examines the impact of real fires on reinforced concrete structures, particularly analyzing cases.

In particular, it has been established that the burnout rate of fire load progresses at a constant speed, with an almost linear relationship that is independent of the fire phase [6].

Article [7, 8] examines the physicochemical processes occurring at the interface between fire protection coatings and structural materials, as well as the effect of heating temperature on the thermal conductivity of the coating [9].

Thermochemical processes in concrete and reinforced concrete under high temperatures are also considered. Cement hydration is an exothermic process. At elevated temperatures, the rate of hydration can change, which in turn affects the final properties of the concrete. For example, the use of special additives can accelerate concrete hardening in low-temperature conditions [10].

At low temperatures, water in concrete can freeze, leading to ice formation and an increase in volume, which may cause internal structural damage. To prevent this, special antifreeze additives are used to lower the freezing point of the water in the concrete mix [11].

In reinforced concrete structures, heating can cause the steel reinforcement to expand, leading to additional stresses and possible bond failure between the concrete and the steel [12]. At high temperatures, the bond strength between reinforcement and concrete is reduced, weakening their composite action. Study recommends the use of deformed (ribbed) reinforcement bars in heat-resistant concrete to improve adhesion.

Due to their ability to withstand high temperatures, reinforced concrete structures can retain their load-bearing capacity even at temperatures exceeding 1000 °C. However, prolonged exposure to high heat requires the use of special insulating materials or heat-resistant concretes with appropriate aggregates [13, 14].

Repeated cyclic loading can cause the accumulation of microdamage, which may eventually result in fatigue failure of the material. Studying the kinetics of damage accumulation under cyclic loads is essential for assessing the long-term durability of materials [15 – 17].

A study published on arXiv proposes a novel approach to automated damage assessment of buildings using multi-temporal photogrammetric point clouds. A machine learning model trained on virtual laser scanning data enables high-accuracy classification of damage levels (severe, extreme, destruction) with an accuracy of 92.0 %–95.1 %. This approach shows great promise for rapid post-disaster building condition assessment [18].

The RescueNet model, presented in another arXiv study, integrates building segmentation and damage classification based on satellite imagery. By applying a novel loss function, the model significantly improves damage classification accuracy, which is vital for prompt emergency response [19].

Article [20] analyzes the case of a residential building in Chernihiv destroyed by fire resulting from military actions. It considers methods of visual and instrumental inspection, determination of the structural condition, and technical solutions for restoring the building's operational functionality.

Infrared thermography can be used to detect anomalies in the temperature field, which may indicate damage or the loss of thermal insulation properties [21, 22].

An analysis of the literature and regulatory documents indicates that different materials respond differently to high temperatures: concrete undergoes thermochemical transformations, moisture loss, cracking, and delamination; steel reinforcement loses strength and elasticity at temperatures above 400 °C; and wood becomes charred, with its structural strength rapidly decreasing under localized heating [23, 24, 25]. The nature of the damage depends on the fire's thermal regime, duration of exposure, the presence of microcracks, material moisture content, and the type of structural system.

2 Main Part

The aim of the work is to develop scientifically based recommendations for the use of non-destructive testing methods to identify areas of critical damage in building structures after fire exposure, taking into account the operating conditions during martial law.

Materials. Vertical reinforced concrete slabs measuring 140 mm in thickness, 3270 mm in height, and 1180 mm in width – originally used as internal partitions between rooms in a public facility – were selected as the test specimens for the experiment.

The tests were conducted using a model compartment with a fire load consisting of rubber products – specifically, two 13-inch passenger car tires, with a total weight of 14 kg.

Prior to testing, 28 chalk marks were applied to the vertical surface of the reinforced concrete slabs at four heights above the floor level: 0.5, 1.0, 1.5, and 2.0 meters (Fig. 1).

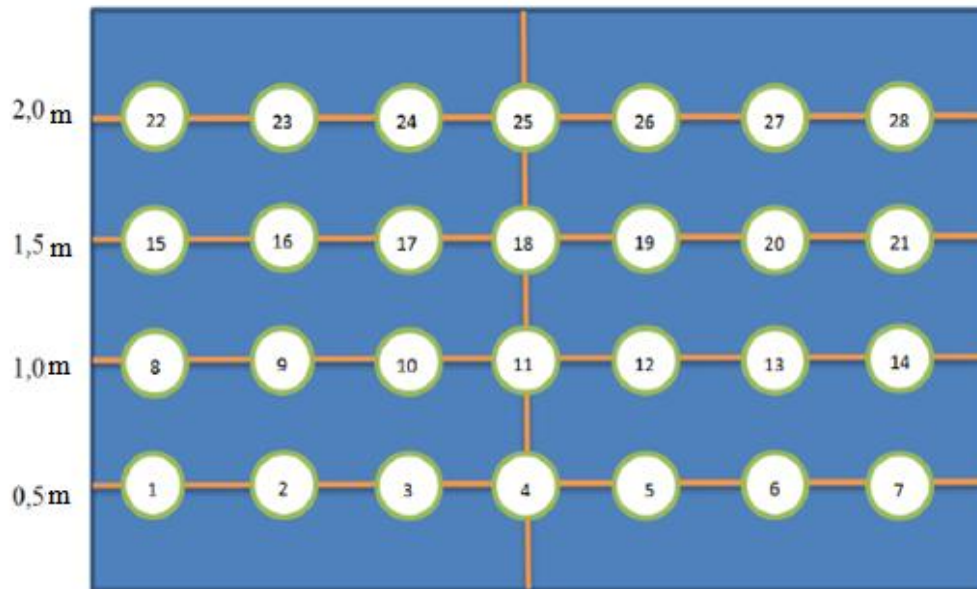


Fig. 1. Location of measurement points

To minimize discrepancies in the measured values, a series of five measurements was performed at each of the 28 designated points of the model compartment using the Schmidt hammer method for strength determination. The results were then averaged.

During the fire test, the temperature of the concrete structure was monitored using measurement equipment, namely a FLIR infrared imaging device and a Stanley thermal detector. The duration of fire exposure was recorded with a stopwatch.

The interpretation of the experimental results was carried out taking into account the spatial and planning features of the facility where the fire occurred.

Study conditions:

1. Ambient temperature – 25 °C.
2. Atmospheric pressure – 100.5 kPa.
3. Relative humidity – 45 %.

Before and after the test, measurements of the strength indicators on both the front and back sides of the reinforced concrete structure were conducted in accordance with the scheme shown in Figure 1.

The fire test lasted 40 minutes, during which the surface temperature of the reinforced concrete structure exceeded 500 °C.

Figures 2–5 show the change in concrete strength at heights of 2.0, 1.5, 1.0, and 0.5 meters, respectively. These graphs illustrate the influence of thermal loading depending on the measurement height, demonstrating a gradual reduction in concrete strength toward the fire source. This visualization makes it possible to identify areas of the most intense thermal impact, which may require additional inspection or structural reinforcement.

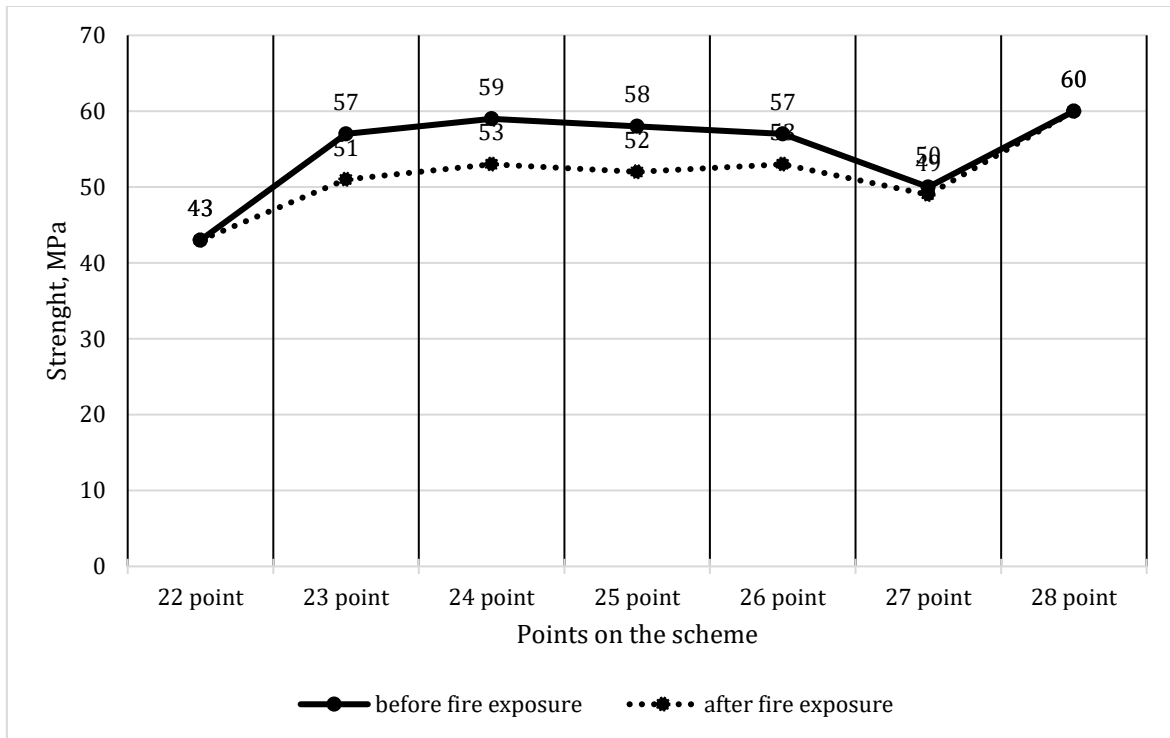


Fig. 2. Change in strength at 2.0 meters

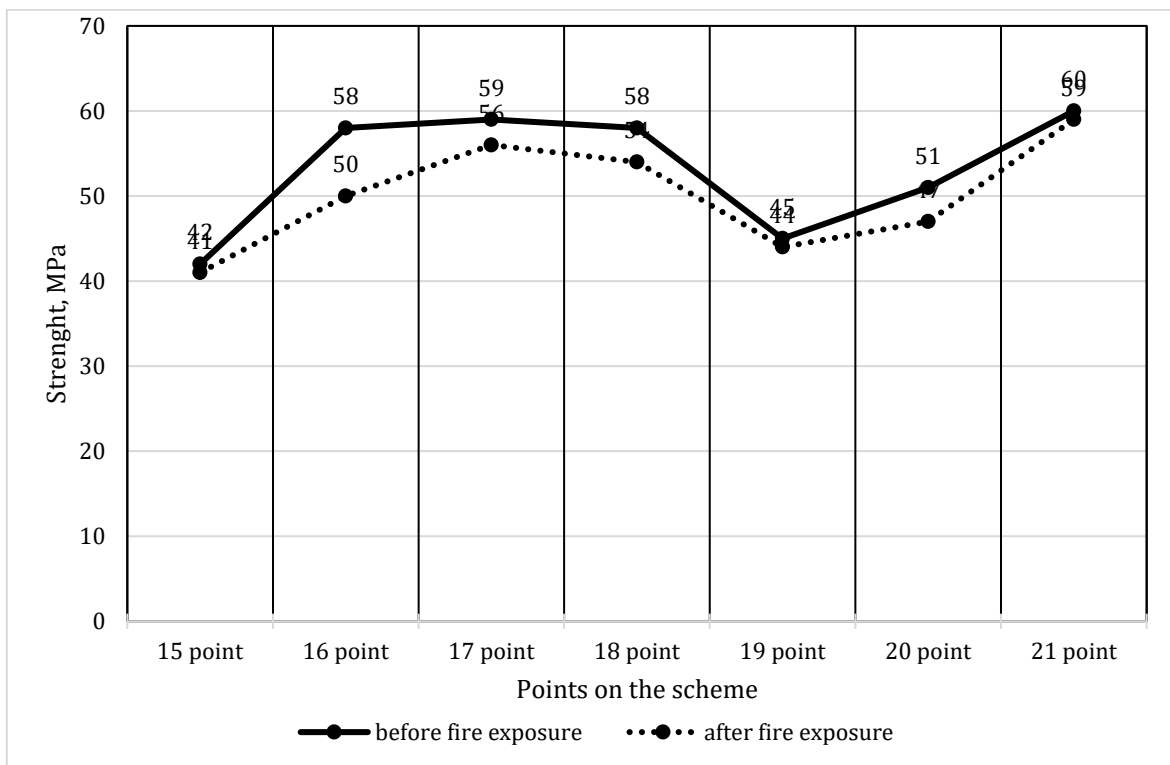


Fig. 3. Change in strength at 1.5 meters

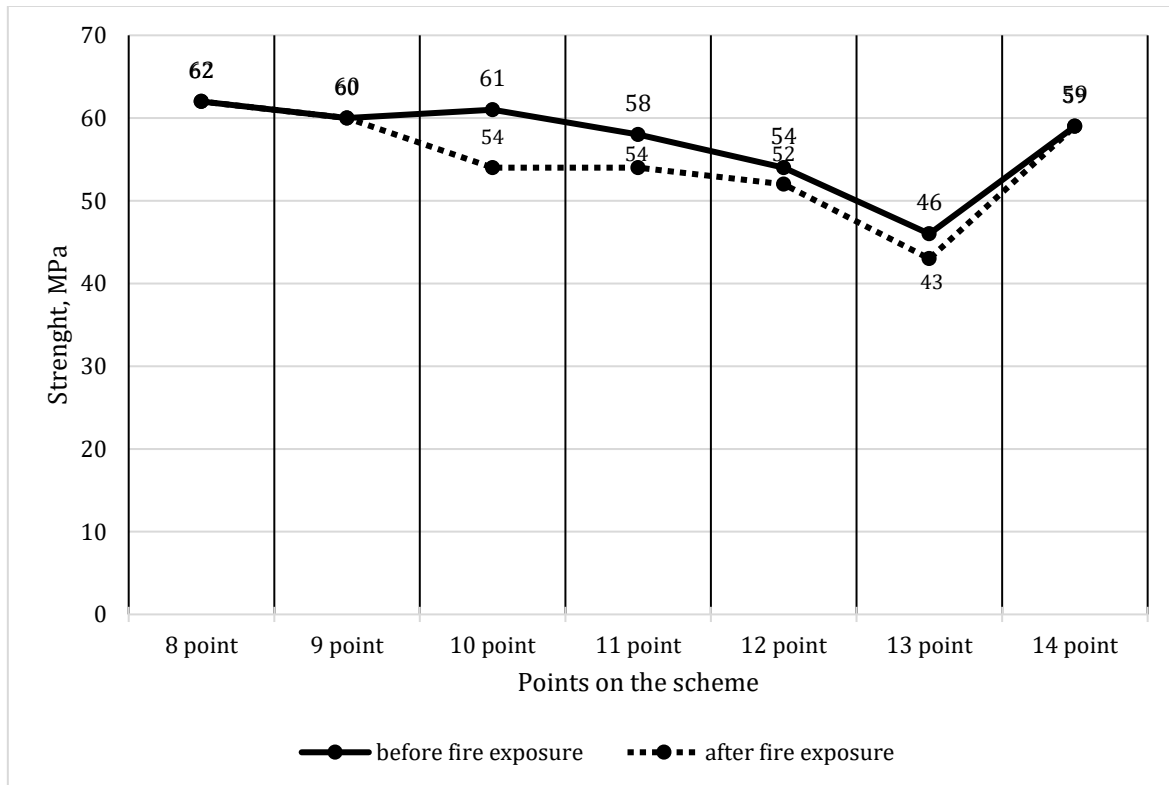


Fig. 4. Change in strength at 1.0 meters

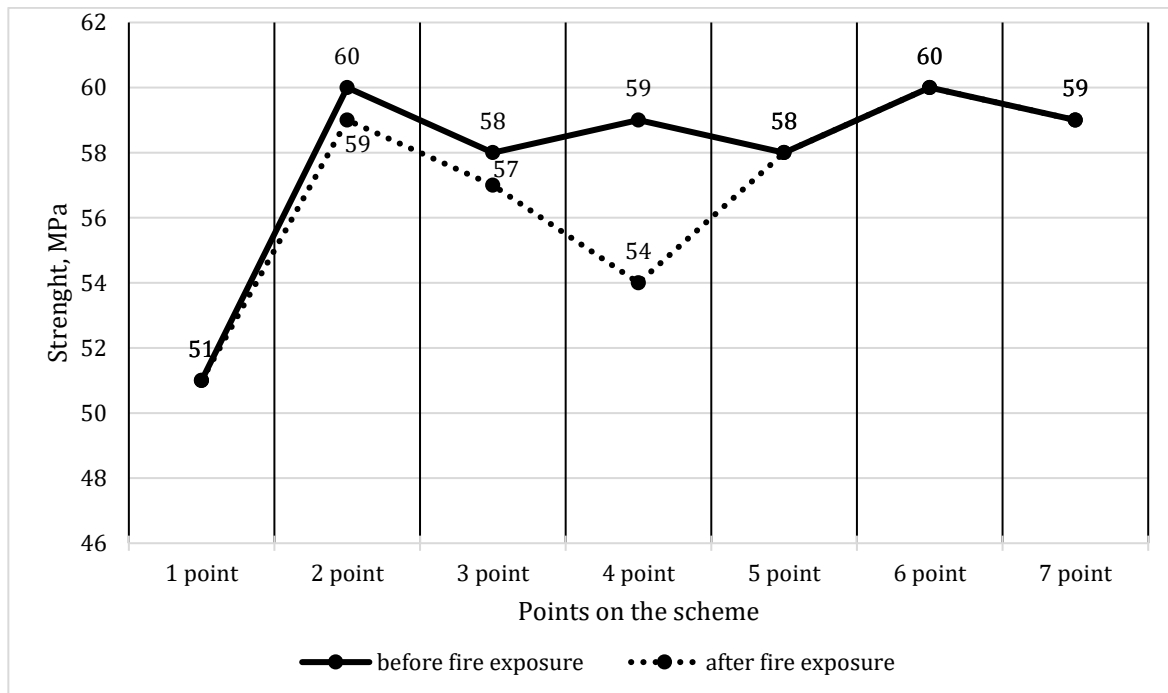


Fig. 5. Change in strength at 0.5 meters

After the test, the formation of a pronounced cellular cone on the surface of the reinforced concrete structure was visually observed (Fig. 6), as well as the layering of incomplete combustion products (soot) on the surface.

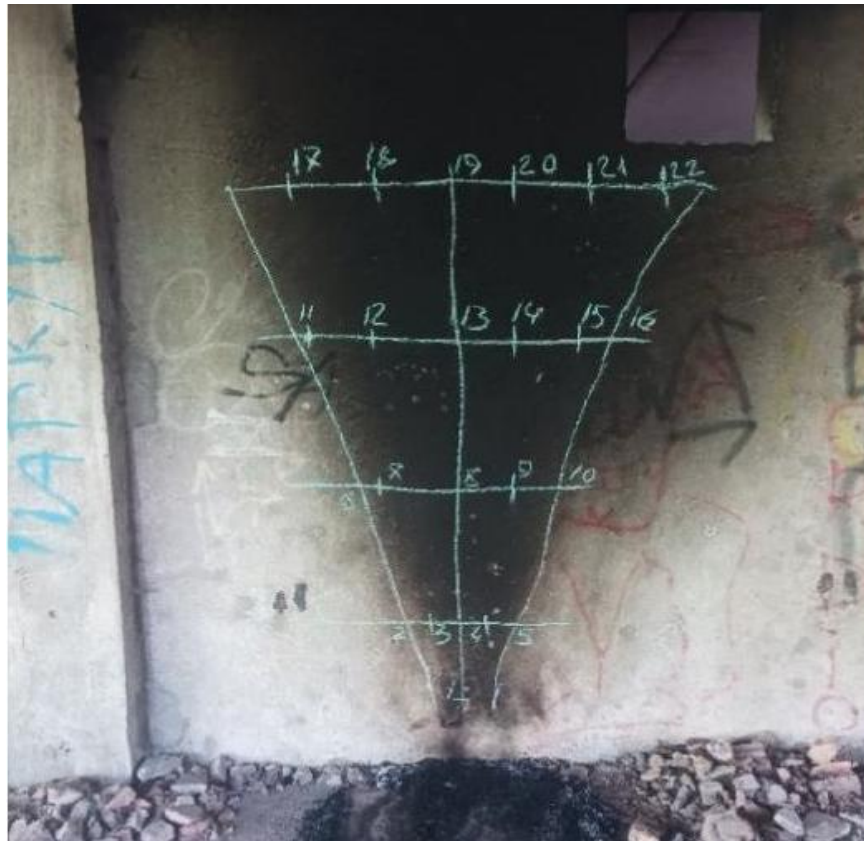


Fig. 6. Cellular cone

The average strength in the cellular cone of the reinforced concrete slab was determined, which was 56.0 MPa before the tests. The average strength value in the cell cone after the tests was 51.64 MPa. The loss of strength in the core was approximately 7.79 %;

Before and after the tests, the strength values of the back (rear) side of the reinforced concrete slab were measured. It was found that there was no loss of absolute strength.

Table 1 shows the main factors affecting the degree of damage to structures during a fire.

Table 1. The main factors affecting the degree of damage to structures during a fire

Factor	Impact on structural damage
Exposure temperature	Determines the depth of material heating and critical changes in physical and mechanical properties
Duration of the fire	The longer the high temperature is applied, the greater the volume of the structure that is thermally damaged
Type of construction material	Reinforced concrete, steel, wood - they react differently to heat and have different fire resistance limits
Presence of a protective layer (concrete/plaster)	Reduces the rate of heating and deformation of internal elements
Preliminary technical condition of the structure	Cracks, monolithic disruption, corrosion of reinforcement increase the risk of loss of bearing capacity
Moisture content of materials	Moisture can cause vapour pressure in concrete, which can lead to spalling and cracking
Type and quantity of combustible load	Determines the intensity and temperature of combustion in the room
Construction configuration and layout	Affects fire spread, heat accumulation and ventilation
Presence of holes/cracks	Accelerates the temperature spread deep into the structure
External conditions (wind, air temperature)	They can both increase and decrease the intensity of fire exposure

Factors affecting the extent of structural damage after a fire include the temperature of the fire, the duration of the fire, the type of materials and the structural design of the building. High temperatures are a major factor in the degradation of materials, particularly concrete and metal, where charring, cracking and deformation can occur. The duration of exposure to high temperatures also plays an important role, as the longer a structure is exposed to fire, the more damage it will sustain. The type of structural system and materials used in a building determine its fire resistance. Also, important are the presence of microcracks, humidity and other operating conditions that can exacerbate fire damage. In general, these factors interact with each other and determine the extent of damage to structures after a fire, which in turn affects the decision to restore or reconstruct them.

3 Conclusion

Fire exerts a multidirectional impact on building structures, altering their physical and mechanical properties, geometric characteristics, functional reliability, and load-bearing capacity. Depending on the temperature regime, duration of combustion, material type, structural system characteristics, load conditions, and pre-fire operating factors, structural elements may experience varying degrees of damage – from minor surface charring to complete loss of load-bearing capacity. Common manifestations of thermal impact include cracking, delamination, surface charring, deformation, and reinforcement corrosion in reinforced concrete. High temperatures also cause degradation of the bonds between constituent materials, changes in porosity, and a reduction in both strength and elastic modulus.

The following results were obtained:

1. An analysis was carried out on the changes in the structure and physico-chemical properties of concrete under thermal exposure. It was found that high temperatures lead to a significant decrease in strength, up to the complete failure of the structure.
2. Among the mechanical non-destructive testing methods, the rebound hammer method was chosen to compare the concrete strength directly at the fire site, as it is more accessible, allowing for faster testing and the ability to obtain preliminary results.
3. The obtained material strength data reflect the extent of changes in the physical properties of concrete. These data are collected at the fire site and allow for the identification of fire temperature zones or dominant directions of heat flow. By analysing the strength indicators, it is possible to determine the most damaged areas and the degree of structural damage, enabling the identification of the most probable fire origin.

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