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DEFINING PATTERNS IN HEATING A REINFORCED CONCRETE COLUMN UNDER THE EFFECT OF A STANDARD FIRE TEMPERATURE REGIME

This study investigates the process of heating a fragment of a reinforced concrete column under standard fire temperature conditions. The task addressed relates to the lack of data on temperatures at characteristic points of the cross-section of reinforced concrete columns during their heating according to the standard temperature curve, which complicates the refinement of calculation models of heat transfer and assessment of fire resistance of structures.

This paper identifies the features of heating a fragment of a reinforced concrete column based on the results of experimental tests in a small-sized fire furnace without applying mechanical load. Temperatures were recorded at six characteristic points of the cross-section of the studied sample, in particular at the level of the reinforcement, in the center of the cross-section, at the control point of the semi-diagonal, and at points close to the concrete surface. It was established that the maximum temperatures at the surface points reached 528°C, and in the reinforcement zone – 506°C, while in the central part of the cross-section they were equal to 468–487°C.

The results showed the absence of local overheating in the planes of thermocouple placement, the formation of a regular temperature gradient in the concrete cross-section during standard fire exposure. A feature of the results is the experimental determination of temperatures at several characteristic points of the column cross-section, which allows a more accurate assessment of the real temperatures in the reinforcement and concrete during a fire.

The findings are associated with the radiation-convective heat exchange between the concrete surface and the flame, as well as with the relatively low thermal conductivity and thermal inertia of the concrete material. Statistical processing of the results showed that the relative deviation of temperature values does not exceed 6.7% while the values of the Cochrane Fisher and Student criteria are less than critical.

The obtained experimental data could be used to further determine the fire resistance limit of reinforced concrete columns and refine the calculation models of heat transfer

***Keywords:** fire, reinforced concrete, column, fire exposure, temperature, sensors, measurements, experiment, combustion*

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1. Introduction

Assessment of fire resistance of building structures is one of the key areas of ensuring fire safety of modern buildings. According to international fire safety studies, a significant part of building destruction is associated with the loss of load-bearing capacity of the main structural elements during fires, as a result of their heating to critical temperatures. During a fire, the temperature of the gas environment can exceed 900–1000°C, which leads to a sharp decrease in the strength of reinforcement and concrete. Reinforced concrete columns are the main load-bearing elements of multi-story buildings;

therefore, their behavior under fire conditions has a decisive influence on the overall safety and stability of the building.

During the action of high temperatures, complex physicochemical processes occur in reinforcement and concrete, which are accompanied by degradation of the material structure, a decrease in strength, the formation of cracks and stiffness of the structure. Methods for calculating the fire resistance of reinforced concrete elements are based on critical temperatures for steel and concrete and the thermal conductivity of materials.

Most modern research and practical tests are guided by the standards implemented in Ukraine – EN 1363-1:2020 and EN 1365-4:2022. The standard defines approaches to determining the critical temperature of reinforcement and reducing the mechanical characteristics of steel and concrete at elevated temperatures. The methodologies described in EN 1992-1-2 (Eurocode 2) are used to compare calculations using different models. However, the thermal problem is solved by calculations that take into account averaged values for composite materials. Therefore, more accurate results are derived from experiments on heating building structures.

The fire resistance of reinforced concrete building structures largely depends on the nature of their heating during a fire and the temperature distribution in the cross-section of the sample. The temperature state of concrete and reinforcement determines the rate of decrease in their strength and affects the overall load-bearing capacity of the structure.

Therefore, studies on the processes of heating reinforced concrete building structures during a fire are of practical importance since the results could be used to refine methods for calculating the fire resistance of reinforced concrete building structures, for increasing the level of fire safety of buildings and structures, and for improving regulatory approaches to their design.

2. Literature review and problem statement

Reinforced concrete columns are the main load-bearing elements of frame buildings, on which their stability during a fire depends. Despite the constant development of computational methods for assessing the fire resistance of reinforced concrete building structures, the reliability of the results of calculation models without experimental verification remains insufficient [1]. The issue of solving this problem in a global dimension is considered in work [2]. However, in those studies attention focuses on methodological approaches and equipment for testing reinforced concrete structures.

In study [3], the influence of elevated temperatures on the destruction of reinforced concrete columns and the mechanisms of loss of their load-bearing capacity after a fire is described. The work analyzed temperature fields and determined critical temperatures at which the reinforcement loses its ability to work as a load-bearing element. However, most attention is on the assessment of fire-damaged elements. It is advisable to investigate the dynamic nature of heating and experimental measurement of temperatures at control points of a column fragment under a standard fire temperature regime.

In [4], the fire resistance of reinforced concrete columns was assessed using refined calculation methods, including thermophysical and static calculation of columns without load. Non-stationary heat transfer models were used, taking into account radiation-convective processes in the gas medium and convection inside the structure. However, experimental aspects of heating a fragment of a reinforced concrete column were not taken into account, which would allow us to clarify the real behavior of the structure during standard fire exposure.

In work [5], the behavior of tubular reinforced concrete columns of square cross-section was investigated under the influence of the standard temperature regime ISO 834. The features of the operation of elements during fire and temperature effects were determined. However, detailed temperature measurements were not carried out at characteristic points of the cross-section of the column fragment, which limits the application of the results for local heat transfer analysis.

In [6], an experimental study of changes in the properties of concrete at elevated temperatures was carried out. Generalized dependences of the modulus of elasticity and changes in strength were presented. However, the dynamics of heating inside the concrete cross-section during fire were not analyzed. Accordingly, it is not possible to compare local temperature indicators with real conditions of ISO-effect.

In work [7], an experimental test of reinforced concrete columns under one-sided fire exposure of 900°C with different layers of gypsum thermal insulation was performed. Despite obtaining valuable data on the effect of insulation, the authors did not consider internal temperature gradients in the depth of the concrete cross-section without additional protective layers, which differs from the goal set in this work.

Paper [8] reports the results of a study on the residual bearing capacity of reinforced concrete columns after exposure to non-standard and standard fire regimes. Attention is paid to mechanical characteristics after cooling. However, study [8] does not provide a detailed analysis of temperature fields in the cross-section of columns during heating according to the standard ISO temperature curve. The work does not contain experimental data on the temperature distribution at characteristic points of the cross-section of the samples during their heating, which limits the possibility of analyzing the features of heating of reinforced concrete columns during a fire.

In [9], the influence of high temperatures on the operation and damage of reinforced concrete elements in nodal connections was considered. At the same time, despite the complexity of the study, the authors did not conduct experimental measurements of temperatures inside the column cross-section, which does not make it possible to use the work for the analysis of temperature fields in a column fragment.

Thus, papers [1–10] report important results on the thermal and mechanical behavior of reinforced concrete structures during fire. However, experimental measurements of temperatures at specific points of the column fragment cross-section under the influence of a standard temperature curve remain insufficiently studied. This limits the possibilities of refining the calculation models of heat transfer and assessing the real fire resistance of structures.

Taking into account the above, data on the heating of the internal layers at characteristic points of the reinforced concrete column cross-section under standard fire exposure remain insufficiently studied, which necessitates the need for appropriate experiments.

3. The aim and objectives of the study

The purpose of our study is to determine the patterns of heating the cross-section of a reinforced concrete column fragment during its heating under the standard temperature regime of fire based on the experimental determination of temperatures at characteristic control points.

This will make it possible to use the obtained experimental data to refine computational heat transfer models and conduct a calculated determination of the fire resistance limit of columns.

To achieve this aim, the following objectives were accomplished:

– to describe the process of heating the furnace chamber during an experimental study of heating a fragment of a reinforced concrete column;

– to determine the temperatures at characteristic control points of the cross-section of a reinforced concrete column fragment during heating under the standard temperature regime of fire;

– to verify the resulting data.

4. The study materials and methods

The object of our study is the process of heating a fragment of a reinforced concrete column under the conditions of a standard temperature regime of fire.

The principal hypothesis assumes that a small-sized fire installation provides a uniform and reproducible temperature regime, and the temperature fields in the column cross-section can be reliably determined experimentally.

The study assumes the uniformity of the thermophysical characteristics of concrete and the absence of mechanical loading.

The following simplifications were adopted in the study:

– mechanical loading was not taken into account;

– the thermophysical characteristics of reinforcement and concrete were assumed to be uniform;

– the effect of cracking on the temperature distribution was not taken into account;

– heating was considered symmetrical relative to the column cross-section.

Fragments of reinforced concrete columns of square cross-section were manufactured in advance at a reinforced concrete products factory. Geometric parameters – 200 × 200 mm and a height of 1000 mm.

The actual dimensions of the three test specimens were:

– specimen 1 – 198 × 199 × 999 mm;

– specimen 2 – 197 × 199 × 997 mm;

– specimen 3 – 199 × 196 × 998 mm.

The reinforced concrete column is made of concrete of class C 40/45 (B40). The composition of the concrete mixture per 1 m^3 included: Portland cement of the "500" brand – 460 ± 10 kg; quartz sand 660 ± 10 kg; granite crushed stone 1150 ± 10 kg; water. Water-cement (W/C) ratio: W/C = 0.3 × (water – 165 ± 10 kg) with the same fractions of granite aggregate (crushed stone) – 10–20 mm.

The components for the concrete mixture were dosed using factory-made weighing batchers. The concrete mixture was mixed in a free-fall concrete mixer with a volume of 0.75 m^3. The concrete mixture was compacted using deep vibrators.

Reinforcement was performed with working reinforcement of class A 500 C with a diameter of 14 and 25 mm and clamps of class A 240 C with a diameter of 8 mm. Before testing, the fragments were aged for 28 days under normal hardening conditions.

Fig. 1 shows the reinforcement scheme of the fragment for testing.

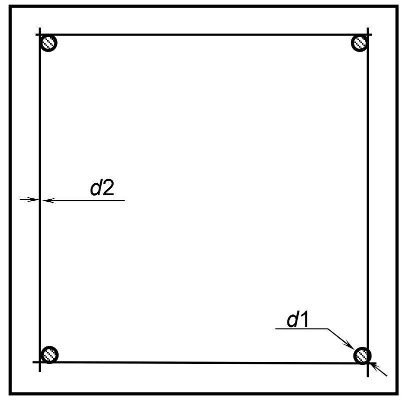


Fig. 1. Reinforcement scheme of the fragment for testing: d_1 – working reinforcement of larger diameter, d_2 – working reinforcement of smaller diameter

The structure was manufactured using standard collapsible formwork. The samples were in the formwork for seven days. After demolding, the fragments were stored for 28 days.

After 28 days of aging, the fragments were stored under normal temperature and humidity conditions until the start of the tests.

The samples were stored in a closed room, then they were transported to the test site and installed in a fire furnace (Fig. 2).

Fig. 2. Fragment of a reinforced concrete column made in a small-sized fire furnace

The test methodology implied the influence of the standard temperature regime of fire during heating of a fragment of a reinforced concrete column in a small-sized fire furnace. Subsequently, based on experimental data, the fire resistance limit is estimated by calculation.

The experiments were carried out in a small-sized fire furnace at the National University of Civil Defense of Ukraine under the standard temperature regime of fire in accordance with European requirements for fire resistance tests.

The ambient temperature during the experiment was 26 ± 1°C, humidity – 58%, wind – 1–3 m/s.

The fragment was placed in the central part of the installation. The upper part of the installation is covered with a lid. Mineral wool and lime cord were used for tightness. Fig. 3 shows a diagram of the installation of the test specimen.

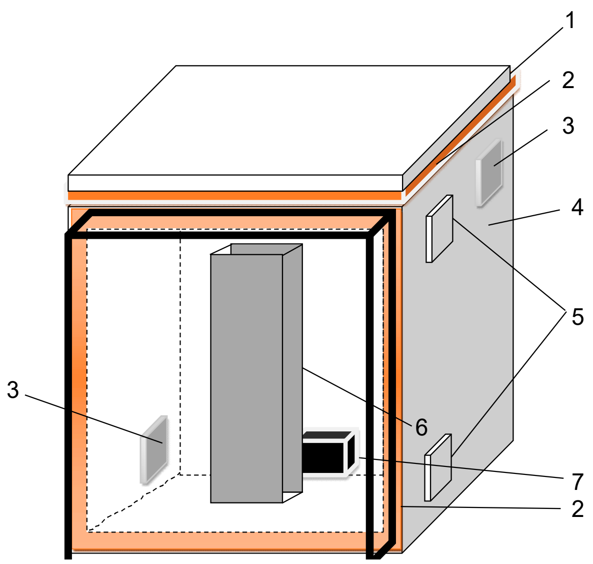


Fig. 3. Scheme of installation of the test sample: 1 – cover covering the upper part of the installation; 2 – seal made of mineral wool and lime cord; 3 – burners creating the temperature regime in the furnace chamber; 4 – furnace enclosure; 5 – places for burners not used during fire tests; 6 – test sample; 7 – hole for the exit of combustion products

During the testing of the fragment, two burners were used, located at the top and bottom of the far part of the installation. The burners that generated flame torches were placed on both sides of the test specimen in the upper and lower parts of the furnace (Fig. 3). During the tests, the places for the burners that were not used were hermetically sealed.

Before the start of the tests, thermocouples were installed in the space of the furnace chamber and on the reinforced concrete column sample:

– three TXA thermocouples are located in the furnace chamber to control the temperature regime and its compliance with the standard;

– 6 thermocouples are placed inside the column fragment: one in the middle of the column cross-section; two – in the closest place to the outer surfaces of the specimen, one in the corner of the column, the other – in the center of the side face; two – at the level of the reinforcement (0.03 m from the surface), one on the main reinforcement, the other – on the auxiliary; one – at the control point – in the middle of the semi-diagonal (Fig. 4).

According to the devised methodologies, the measuring equipment must be installed before the tests.

The limit state of loss of bearing capacity occurs on the basis of the corresponding calculated interpretation of the measurement results during the tests.

The occurrence of the limit state is recorded by the heating temperature of the reinforcement using the "critical temperature" criterion.

Table 1 systematizes the measuring equipment used during the study of heating a fragment of a reinforced concrete column.

To record the temperature in the furnace and in the studied fragment, thermocouples TXA-2388 with a wire diameter of 1.25 mm were used (Fig. 5). They can be used to measure the temperature in the range from 0 to 1300°C.

All analog-to-digital signal converters of temperature control sensors are located in the combined temperature calculation unit (Fig. 6).

The schematic diagram of the combined temperature calculation module is shown in Fig. 7.

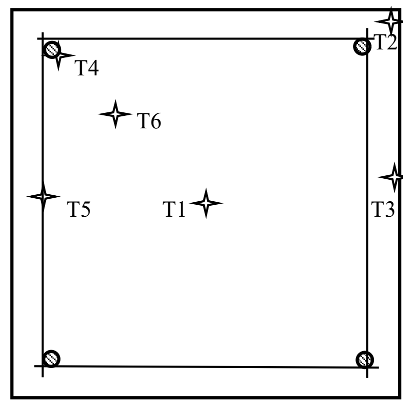
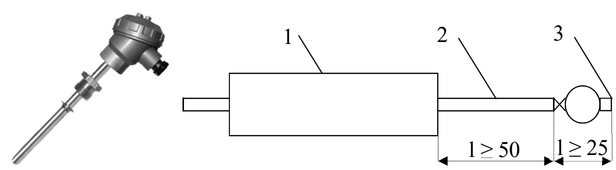


Fig. 4. Scheme of the location of measuring equipment in the cross-section of the fragment to be tested: T1 – thermocouple in the middle of the column cross-section; T2 – thermocouple in the closest place to the outer surfaces of the sample, in the corner of the column, and T3 – thermocouple in the center of the side face; two at the level of the reinforcement (0.03 m from the surface), T4 – thermocouple on the main reinforcement, T5 – thermocouple on the auxiliary; T6 – thermocouple at the control point in the middle of the semi-diagonal



a *b*

Fig. 5. Thermocouple for measuring temperatures in the working space of the furnace and in the sample under study: *a* – general view; *b* – diagram: 1 – heat-shielding shell; 2 – protective casing; 3 – measuring junction

Table 1

Measuring instruments

No. of entry	Name of equipment or appliance	Serial number	Measurement range	Measurement error
1	Measuring ruler	–	from 0 mm to 1000 mm	± 1 mm
2	Stopwatch SOS pr-2b-2-000	3401	from 0 s to 60 s, from 0 s to 60 min	±(0.4 / 60 τ) ± ± (0.4 + 1.5 / 3540 (τ – 60))
3	Psychrometer aspiration MV-4M	14689	from 10% to 100% from – 10°C to 50°C	± 4% ± 0.2°C
4	Caliper SHhTs-1	3339340	from 0 mm to 125 mm	± 0.1 mm
5	Aneroid barometer M67	797	600–800 mm Hg.	± 1 mm Hg.
7	Anemometer ASO-3	12952	from 0.3 m/s to 5 m/s	± (0.1+0.05V) m/s
8	Thermocouple TXA-2388	2388 with ADC module	from 0 to 1300°C	± 2.0°C

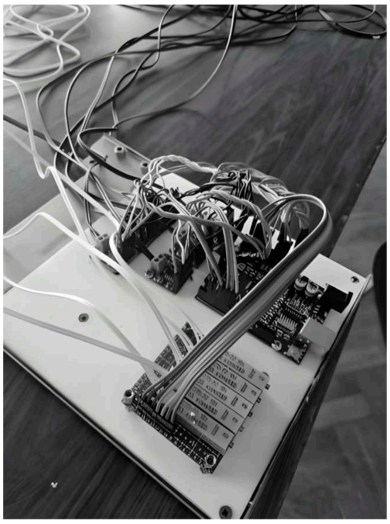


Fig. 6. Combined temperature calculation module

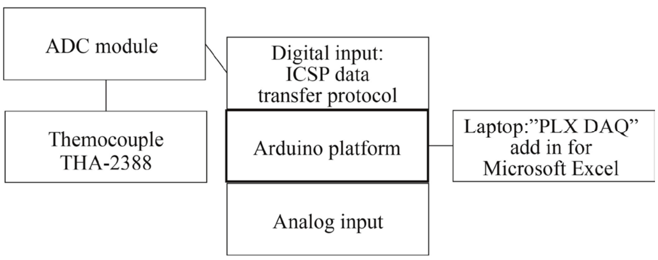


Fig. 7. Schematic diagram of the combined temperature calculation unit

To record digital temperature readings at the thermocouple installation locations, an analog-to-digital conversion (ADC) module for the thermocouple signal based on the max. 31855 chip was used, which makes it possible to convert the analog digital signal of the thermocouples into a digital one with a maximum temperature value of up to 1350°C. The module transmits the signal to the Arduino platform via a digital input. The signal from the thermocouples is fed to the analog input and processed by the Arduino microprocessor.

The combined temperature calculation unit shown in Fig. 6 is specially designed for a small-sized installation, developed at the National University of Civil Defense of Ukraine, and helps measure temperature with a sensitivity of 0.25°C. This device takes into account the temperature of cold junctions and automatically corrects the temperature value [11].

To process the obtained information, the PLX DAQ plugin for Microsoft Excel (USA) was used, which allows for real-time recording of temperature values and plotting graphs.

To determine the adequacy of experimental data during testing of reinforced concrete columns, statistical criteria similar to those used to verify the results of testing walls and slabs were selected.

Fisher's F-test (1). The variance of adequacy is the deviation between the indicators of a particular thermocouple and the average temperature value in all three experiments with respect to the temperature measurement location (2).

Fisher's F-test is used to consistently compare the variances of the temperature indicators of each thermocouple located in the design with the variance of the reproducibility of experimental studies. The use of Fisher's criterion makes it possible to verify the hypothesis about equality of general variances, the distribution of temperatures at each minute of testing

$$F = \frac{S_{xy}^2}{S_y^2}, \tag{1}$$

where S_{xy}^2 is the adequacy variance, S_y^2 is the reproducibility variance.

The adequacy variance is calculated as the deviation between the readings of a specific thermocouple and the average temperature value in all three experiments with respect to the temperature measurement location

$$S_{xy}^2 = \frac{\sum_{i=1}^{n}\left(x_i - y_i\right)^2}{n}, \tag{2}$$

where n is the number of temperature measurements, y_i is the average temperature value in all three experiments for the temperature measurement location, x_i is the reading of a specific thermocouple during the test.

The reproducibility variance is calculated as the deviation of the minimum and maximum temperature at the location of a specific thermocouple across all experiments, taking into account the thermocouple error (3)

$$S_y^2 = \frac{1}{n}\sum\nolimits_{i=1}^{n}\left(v_j - \overline{v} + 1\right)^2, \tag{3}$$

where n is the number of temperature measurements, $\overline{v}+1$ is the deviation of the minimum and maximum temperature at the location of a specific thermocouple for all experiments, v_j is the thermocouple performance directly at the measurement location.

So, 6 values of the adequacy variance were alternately compared with the reproducibility variance, and the Fisher criterion (F) was calculated.

Student's t-test (4), (5), taking into account the relativity variance (3): the variances of the average values of the thermocouple performance during the experiment at the location of each of the 6 thermocouples were alternately compared with 2 variances of other experiments for the column. 6 criterion values were obtained.

To compare the results of the experiments in this study, the Student's t-test was used:

$$t = \frac{\overline{y}_1 - \overline{y}_2}{\sqrt{\left(n_1 - 1\right)\cdot S_1^2 + \left(n_2 - 1\right)\cdot S_2^2}} \cdot \sqrt{\frac{n_1 \cdot n_2 \cdot \left(n_1 + n_2 - 2\right)}{n_1 + n_2}}, \tag{4}$$

$$\overline{y}_{1,2} = \frac{1}{n}\sum_{i=1}^{n} y_i, \tag{5}$$

where S_1^2, S_2^2 – estimates of the variances of the test between themselves and in a specific experiment, calculated similarly to the calculation of the Fisher criterion, $n_{1,2}$ is the number of degrees of freedom.

5. Results of an experimental study of heating the internal layers of a fragment of a reinforced concrete column

5.1. The process of heating the furnace chamber during experimental studies on heating a fragment of a reinforced concrete column

During the tests, photo and video recording of the heating process was carried out (Fig. 8).

Fig. 8. View of the furnace before the start of the test

As evidenced by the thermocouple heating data (Fig. 9), the linear heating rate of the furnace chamber is consistent with the "standard" fire temperature curve and is within standard limits. Upon reaching 940°C, a steady-state mode is set, using furnace heating power control. The test duration is 65 minutes.

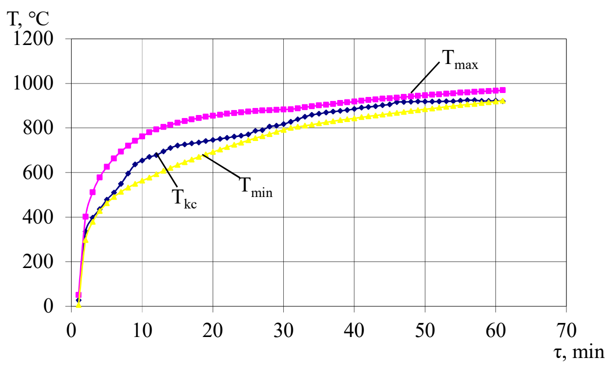


Fig. 9. Linear heating rate of the furnace chamber during heating of a fragment of a reinforced concrete column: T_{min}, T_{max} — limit limits of tests under the standard temperature regime of fire; T_{kc} — average thermocouple indicator during fire tests in the chamber of the fire furnace

The studies are limited to 60 minutes, since further the temperature regime can approach the stationary one.

5. 2. Results of the study of temperatures at characteristic control points of the cross-section of a fragment of a reinforced concrete column during heating under the standard temperature regime of fire

Fig. 10–13 show the results of temperature change at the points shown in Fig. 4 during the test time.

From Fig. 9–13 it became known that in the concrete cross-section there is a regular formation of temperature gradients. At the points closest to the surface of the sample (T2, T3), the highest temperatures (up to 528°C) were recorded.

At the level of the reinforcement, the temperatures (T4, T5) reached 497–506°C, which corresponds to the critical interval of loss of strength of steel.

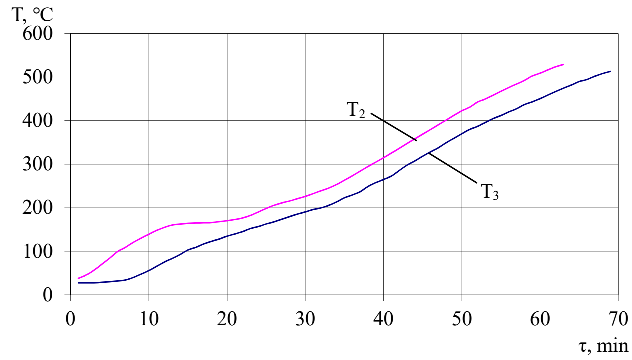


Fig. 10. Results of temperature measurements in the places closest to the outer surfaces of the sample: T_2 — in the corner of the column; T_3 — in the center of the side face

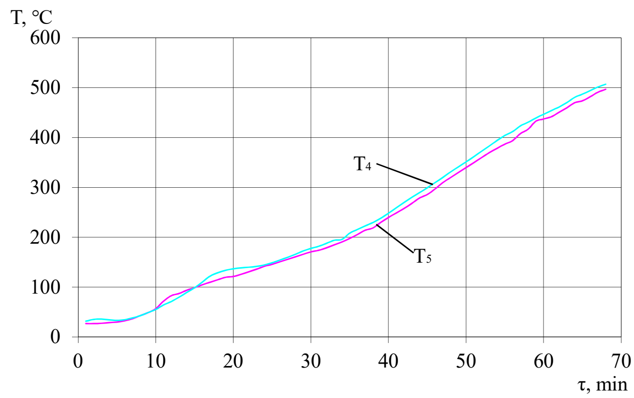


Fig. 11. Results of temperature measurement at the level of the reinforcement of the tested sample: T_4 — on the main reinforcement; T_5 — on the auxiliary reinforcement

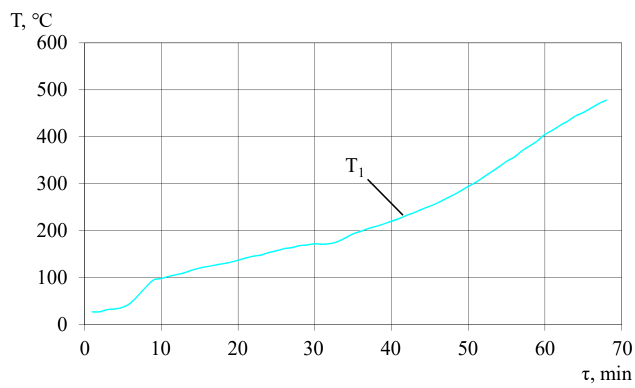


Fig. 12. Results of temperature measurement in the middle of the column cross section — T_1

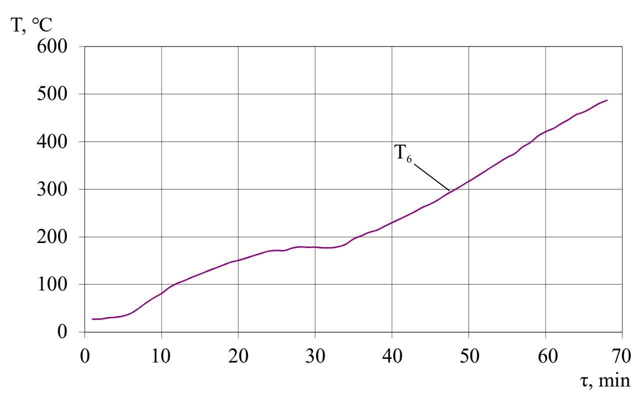


Fig. 13. Temperature measurement results at the control point (in the middle of the semi-diagonal) — T_6

In the center of the cross-section, the temperatures (T1) and at the control point (T6) were lower (468–487°C), which is due to its relatively low thermal conductivity and thermal inertia of concrete.

Our results confirm the absence of local overheating and the formation of a symmetric temperature field.

5. 3. Verification of experimental data

The results of the calculation of statistical criteria are summarized in Table 2.

Table 2

Variance in the parameters of results from fire tests of reinforced concrete columns based on the results of three experiments

Thermo-couple zone	Maximum deviation, °C	Mean deviation, °C	Relative deviation, %	F-Test	Critical value of the F-criterion	T-Test	Critical value of the t-criterion	Q-Test	Critical value of the Q-criterion
T1	18.3	5.5	2.7	0.70	4.49	1.49	2.92	0.33	0.45
T2	21.0	6.7	3.4	0.26		1.42		0.33	
T3	18.0	5.7	2.8	0.33		1.48		0.30	
T4	50.8	19.4	6.7	0.71		2.20		0.41	
T5	22.0	6.0	3.0	0.44		1.55		0.35	
T6	14.5	3.7	2.1	0.44		1.47		0.30	

From the data given in Table 2, it became known that the relative deviation did not exceed 6.7%, the calculated statistical criteria (Student's *t*-test, Cochran's Q-test, Fisher's F-test) did not exceed critical values.

6. Discussion of results based on determining the features of heating the section of a reinforced concrete column fragment

Our results (Fig. 10–13) of temperature changes at control points (Fig. 4) of the structural fragment during the heating time under the standard temperature regime of fire demonstrate the regular formation of temperature gradients in the concrete section during standard fire exposure.

The highest temperatures were recorded at the points closest to the sample surfaces (T2, T3), up to 528°C (Fig. 10). This is explained by direct radiation-convective heat exchange between the concrete surface and the flame.

The temperatures at the level of reinforcement (T4, T5) reached 506°C (Fig. 11), which corresponds to the critical interval of steel strength loss (500–520°C).

In the center of the cross section (T1, Fig. 12) and at the control point of the semi-diagonal (T6, Fig. 13), the temperatures were lower (up to 487°C), which is explained by the relatively low thermal conductivity of concrete and its thermal inertia. The symmetry of the thermal effect is evidenced by the uniformity of heating in the planes of the thermocouples and, accordingly, the absence of local overheating is confirmed.

Statistical processing of the results (Table 2) showed that the relative deviation does not exceed 6.7%, and the values of the F-, t-, and Q-criteria are less than the critical ones. This confirms the reproducibility of the obtained results of experimental studies.

Our results are consistent with the studies listed below. In [5], the behavior of tubular reinforced concrete columns was investigated according to ISO-834, but detailed local temperature measurements at characteristic points of the cross section were not provided. In our study, unlike [5], temperature fields were recorded at six characteristic points, which makes it possible to estimate real gradients; in [3], most attention was paid to the residual bearing capacity after a fire. In this case, the dynamics of heating of the structural element were investigated, which is a necessary prerequisite for further calculation of the limit state; in [6], the temperature distribution in the cross section during heating was not investigated, but the dependences of changes in concrete properties at elevated temperatures were provided. The obtained data of the conducted experimental study complement these results, providing real temperature profiles.

A feature of our results is the experimentally established temperature values at the control points of the cross-section of a fragment of a reinforced concrete column under the standard temperature regime of fire without applying mechanical load, which are accompanied by statistically confirmed reproducibility, the relative deviation does not exceed 6.7% (Table 2).

The use of a small-sized fire furnace (Fig. 3) provided the possibility for conducting experiments at reduced costs and simplified organization of tests while maintaining a controlled temperature regime.

The rational arrangement of thermocouples at the control points of the cross-section allowed us to obtain experimental data on the temperature distribution in the concrete and the reinforcement zone.

The limitations of the study include:

– lack of mechanical load on the sample;

– study of a fragment of the structure, not a full-size column;

– symmetrical thermal effect;

– heating duration of 60 minutes;

– use of concrete of the same class (C40/45);

– failure to take into account the processes of crack formation;

– applicability of the results only for similar thermal conditions and geometric parameters.

The shortcomings that may affect the accuracy or completeness of the results include:

– limited number of experiments (3 samples);

– lack of direct measurements of heat flows;

– lack of numerical modeling for comparison with experimental data.

Further development may consist of the following:

– study of columns under load;

– construction of a numerical model of heat transfer;

– determination of the fire resistance limit by the criterion of loss of bearing capacity;

– study of different classes of concrete and types of reinforcement.

Possible difficulties in further development of the study:

– instability of the temperature regime during long-term tests;

– difficulty in calibrating numerical models;

– increased requirements for the accuracy of measuring equipment.

7. Conclusions

1. Based on the results from solving the problem of describing the process of heating the furnace chamber, it was established that in a small-sized fire furnace the temperature regime corresponds to the standard temperature curve of fire. At a level of about 940°C, temperature stabilization was achieved, which indicates that the necessary conditions are provided for conducting experimental studies and correctly reproducing the standard fire effect.

2. According to the results of solving the task, namely determining the temperatures at the control points of the section of a fragment of a reinforced concrete column, it was established that after 60 minutes of its heating, the temperature in the external zones reaches 513–528°C, in the reinforcement zone – 497–506°C, and in the center of the section – 468–487°C. The formation of a regular temperature gradient was experimentally confirmed in the column section taking into account the location of the reinforcement. It was found that the temperature difference between the surface and central zones is up to 60°C, and the temperature of the reinforcement reaches critical values (about 500°C) within 60 minutes, which indicates a possible loss of its strength in the early stages of the fire.

3. Based on the outcomes from verifying our experimental data, it was found that the results are statistically reliable and reproducible: the relative deviation is 2.1–6.7%, and the values of the Cochrane, Student, and Fisher criteria do not exceed the critical ones. This confirms the possibility of using the obtained experimental data as input parameters for engineering calculations of fire resistance and calibration of numerical heat transfer models.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Vadym Yanishevskyi: Conceptualization, Methodology, Supervision; **Alina Perehin:** Investigation, Data curation, Writing – original draft; **Serhii Gonchar:** Formal analysis, Validation; **Oleksandr Nuianzin:** Methodology, Resources; **Oleh Zemlianskyi:** Software, Data curation; **Oleksandr Olefirenko:** Visualization, Writing – review & editing.

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