ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

UDC 614.841

# STUDY OF THE THERMAL EFFECT OF FIRE ON FRAGMENTS OF REINFORCED CONCRETE COLUMNS BASED ON THE RESULTS OF EXPERIMENTAL TESTS

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DOI: 10.32347/2410-2547.2024.112.202-208

The paper analyzes the thermal effect of fire on fragments of reinforced concrete columns based on their heating according to the standard fire temperature regime in a small-sized installation for the study of the thermal effect of fire on building structures. Based on the proposed method, a technique was created that makes it possible to estimate the fire resistance limit of a full-size structure by calculation. The course and results of the conducted fire test are described, and the adequacy and reproducibility of the experimental data are verified. The temperature distribution over the entire area of the fire furnace, the studied fragments was analyzed and the obtained results were processed. The possibility of creating a standard fire temperature regime in the fire furnace chamber has been verified. According to the results of this work, it was established that the heating of the structure at all levels was uniform in the planes of placement of thermocouples, the maximum temperature on the surface was 709 °C, it was observed at the last minute of the experiment and continued to increase linearly, the maximum temperature reached in the center of the rock column was 105 °C, it was observed at the last minute of the experiment and continued to grow linearly; The adequacy of the experimental data was confirmed: the relative deviation did not exceed 4%, and the calculated adequacy criteria (Fisher, Student and Cochrane) were below the critical value.

**Key words:** reinforced concrete column, test, small fragment, compact fire installation, experimental study, temperature, Fisher's test.

**1. Formulation of the Problem.** The main reasons for the destruction of buildings and structures during a fire are open flames and the effect of high temperatures, which lead to rapid heating of building structures. According to [1], the degree of fire resistance of a building is determined by the limits of fire resistance of its building structures and the limits of fire propagation by these structures. In the conditions of the thermal effect of fire, the general stability of the building is disturbed due to the deformation and destruction of individual elements of the building structures. Guaranteeing the limit of fire resistance is one of the important aspects of ensuring fire safety, in particular the evacuation of people in case of fire.

To determine the limits of fire resistance, the most common are full-scale fire tests, the method of tests in special fire test furnaces, experimental-calculation and calculation methods. However, full-scale fire tests are not cost-effective and are extremely rare, even in the most developed countries. Fire tests and parameters of modern test facilities are far from perfect, as there are errors due to the fact that the control of the fuel system and the configuration of the fire furnaces do not ensure full compliance of the conditions of the experiment with the requirements of the standards in this field. In addition, large-sized furnaces are not environmentally friendly, labor-intensive and not always economically feasible. Calculation methods are not able to provide the necessary accuracy, since it is impossible to take into account the characteristics of the behavior of multi-composite material of building structures when heated.

**2. Analysis of Recent Achievements and Publications.** In Ukraine, there are several regulatory documents regarding the assessment of fire resistance of reinforced concrete columns [1-3]. These normative documents define the possibility of carrying out tests without using load on samples of building structures, in particular columns, for which it is impossible to reproduce the load conditions in the laboratory during the tests due to technical reasons. The standards state that it is possible to examine both sample fragments of building structures and structures of designed dimensions. Testing of non-standardized and large-sized structures is problematic, as it requires large financial investments and labor costs, and test furnaces may be smaller than the dimensions of the structures being tested. In addition, it is non-ecological. Therefore, works [4, 5] proposed the idea of conducting an experiment on heating small-sized elements of reinforced concrete structures in a compact fire installation according to the standard fire temperature regime. Then verification of experimental data and calculation is carried out.

In works [6, 7], the limit of fire resistance was established based on the loss of heat-insulating ability of fragments of building structures, and the temperature change along the thickness of the wall structure during the heating process was investigated using a furnace for small-sized thermophysical tests. The design of the furnace provided for the use of one burner to heat the chamber. According to works [8, 9], this affects the uniformity of heating of the structures under study and indicates the imperfection of the structure.

This work is a continuation of the cycle of works, in particular [4, 5], where a small-sized installation is used for conducting experiments to study the thermal effect of a fire on building structures, as well as works [8, 9], which note the influence of the uniformity of heating of the investigated structure during its fire resistance tests. This work shows and analyzes the results of experiments on heating a small-sized element of a reinforced concrete beam according to the standard fire temperature regime.

**3. Problem Statement and its Solution.** The purpose of the work is to obtain the results of temperature distributions on the surface and at integration points in the cross-sections of fragments of reinforced concrete columns for further calculation of their fire resistance limit and to check the reproducibility of experimental data.

To achieve the goal, the following tasks were set and solved:

To describe the stages of creating small fragments of reinforced concrete columns for fire tests.

To describe the methodology and means of conducting experimental tests.

To analyze the temperature regime on the surface and integration points in the sections of fragments of reinforced concrete columns.

To verify the experimental data obtained during the fire test.

To determine the prospects for further research.

**4. Presentation of the main material of the study with a full justification of the results.** To conduct the experiment, a small-sized installation was used to study the thermal effect of fire on building structures [4, 5].

Three fragments of reinforced concrete columns with a cross section of 200x200 mm and a nominal size of 1000 mm, which were manufactured in advance of the test.

Proportions of making fragments (for 1 $m^3$): brand portland cement «500» – 460 ± 10 kg; quartz sand – 660 ± 10 kg; granite crushed stone – 1150 ± 10 kg; water.

The reinforcement corresponded to the ones actually used in the construction of the beams of modern residential buildings made of reinforced concrete. The reinforcement is a class wire Vr-I with a diameter of 5 mm.

Water-cement ratio: W/C = 0,3 ×(water – 138 ± 10 kg);

with the same fractions of granite aggregate (crushed stone) – 5 – 10 mm.

Dosing of components is carried out with the help of weighing dispensers of the factory Concrete mixing installations. The concrete mixture was mixed in a free-fall concrete mixer with a volume of 0,75 m3. The compaction of the concrete mixture is performed by deep vibrators.

Fig. 1 presents a photo of a pre-prepared fragment, sample No. 1, for a full-scale fire resistance test.

The construction was made using standard collapsible formwork.

The samples were in the formwork for seven days. After demolding, the fragment and auxiliary samples were stored for 28 days.

ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

After aging for 28 days, the fragments were stored in normal conditions of temperature and humidity until the beginning of the tests.

**5. Methods of the experiment.** As can be seen from Figure 1, the column samples were transported to the test site and installed in the fire furnace.


Fig. 1. A small-sized fragment of a reinforced concrete column made in advance before the test: 1 fragment of a pre-made reinforced concrete column

The general technique consists in the influence of the standard fire temperature regime during the four-sided heating of the element of the reinforced concrete column, based on which, by calculation, it will be possible to estimate the fire resistance limit of the full-size structure.

Before the start of the test, the date of the study, ambient air temperature, air humidity, wind strength and direction were recorded, which met the regulatory requirements [1-3]. Before starting, the overall dimensions of the sample, the thickness of the sample are measured and the established data are recorded: 3 samples were made:

Sample 1: 200×200×998 mm. Sample 2: 200×200×999 mm. Sample 3: 200×200×998 mm.

The test sample is installed vertically in the geometric center of the furnace chamber of the installation. The front wall of the installation is missing, so it is closed with a cover (Fig. 1.). Mineral wool and lime cord were used for tightness. Fig. 2 shows a diagram of the installation of the test sample and the elements of the installation.

When testing columns, 2 burners are used. They are placed diametrically opposite from the bottom and top of the installation on the opposite walls of the chamber, so that the flame torches cross each other (Fig. 2). During the tests of the columns, places for the burners that were not used were covered with bricks and mineral wool to prevent the exit of furnace gases through these holes.

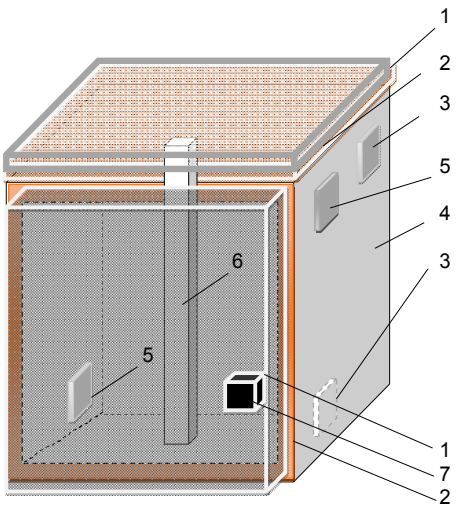


Fig. 2. The scheme of installation of the sample for testing: 1 – cover of the front and upper part of the installation; 2 – mineral wool and lime cord sealant; 3 – places for burners not used during fire tests of walls; 4 – furnace enclosure; 5 – burners that create a temperature regime in the furnace chamber; 6 – sample under investigation, 7 – outlet of combustion products

To conduct the experiment on the heating of small-sized elements, modern means of metrology were used, which passed a timely check. The layout of measuring equipment is shown in Fig. 3.

As can be seen from Fig. 3, the measuring equipment that was installed before the beginning of the tests are placed and numbered as follows: thermocouples T3 and T5 are installed on the heating surface of the sample; on thermocouple T1 in the geometric center and thermocouples T2 and T4 on the lines of symmetry.

Thermocouples were used to measure the temperature in the furnace

TChA-2388 with a wire diameter of 1.25 mm, which can be used to measure temperatures in the range from 0 to 1300°C.

An analog-to-digital conversion (ADC) module, described in [4], was used to obtain digital temperature values in the places where the thermocouple was installed. The PLX DAQ plug-in for Microsoft Excel was used to process the received data, which allows you to see numerical values of

temperature in real time and draw corresponding graphs.

Figure 4 shows the furnace chamber heating graphs according to the readings of each of the installed thermocouples.

As evidenced by the heating data of the thermocouples (Fig. 4.), the linear heating rate of the furnace chamber corresponded to the "standard" temperature curve of the fire, and was within the limits defined by the standard [1]. When the value of 950°C was reached, a stationary mode was established by adjusting the heating power of the furnace. The test lasted 63 minutes.

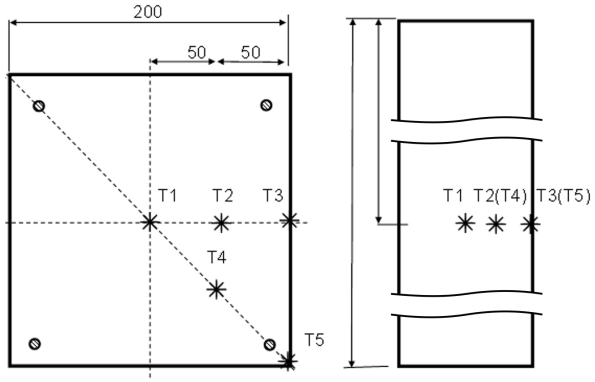


Fig. 3. The scheme of location of measuring equipment in the cross-section of a reinforced concrete column - sample for testing

Studies were limited to 60 minutes, since the temperature regime then approaches the stationary one.

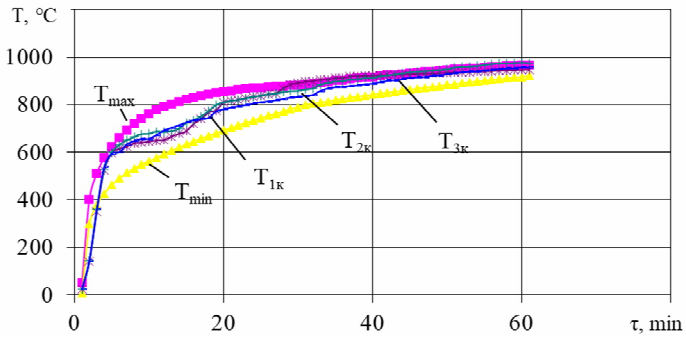


Fig. 4. The linear heating rate of the furnace chamber during the column test: $T_{1k}$-$T_{3k}$ – installed thermocouples in the chamber

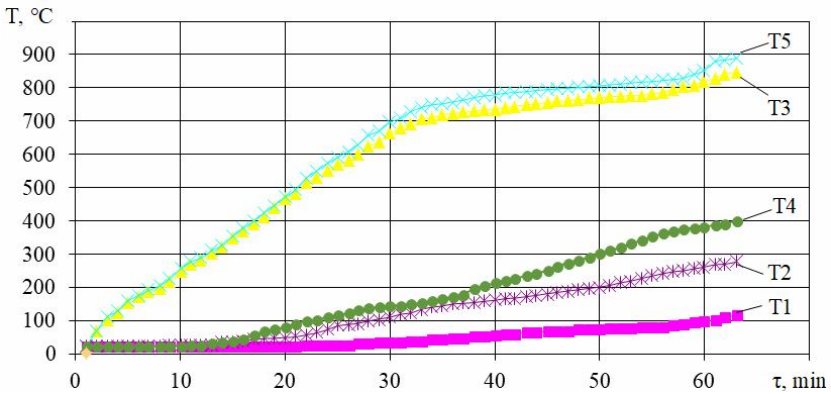


Fig. 5. The results of measuring the temperature of the tested sample: T1-T5 – readings of thermocouples (Fig. 3.)

Figure 5 shows the results of showing thermocouples T1 – T5 inside and on the surface of the reinforced concrete column during the tests.

After analyzing the data obtained from the results of the experiments (Fig. 4), the following conclusions were obtained:

- two gas burners are able to ensure compliance of the temperature regime in the furnace chamber with the "standard" one [1];
- heating of the structure at all levels was uniform in the planes of placement of thermocouples (Fig. 5);

ISSN 2410-2547
Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures. 2024. № 112

- the maximum temperature on the surface of the rock, 709°C, was observed at the last minute of the experiment and continued to increase linearly;
- the maximum temperature at the center of the rock column was 105°C, it was observed at the last minute of the experiment and continued to increase linearly;
- it is necessary to verify the experimental data to confirm their reliability;
- the obtained experimental data are sufficient for further calculation of temperature fields inside the structure and assessment of fire resistance of structures.

In our case, 3 experiments were conducted according to the standard temperature regime of a fire in a small-sized installation to study the thermal effect of a fire on building structures of 3 elements of reinforced concrete columns made under similar conditions from identical materials.

To verify the adequacy of the results of experimental data during column tests, statistical criteria similar to the verification of wall, column, and slab test results were selected.

The results of the calculation of the adequacy criteria are summarized in the table 1.

Table 1

Dispersion parameters of the results of fire tests of reinforced concrete columns based on the results of three experiments

| Thermo-couple zone | Maximum deviation, °C | Average deviation, °C | Relative deviation, % | F-criterion | The critical value of F-crit. | t-criterion | The critical value of t-crit. | Q-criterion | The critical value of Q-crit. |
|---|---|---|---|---|---|---|---|---|---|
| T1 | 23,8 | 7,1 | 4,0 | 2,26 | 4,49 | 1,50 | 2,92 | 0,31 | 0,45 |
| T2 | 28,6 | 7,2 | 3,7 | 2,32 | | 1,17 | | 0,34 | |
| T3 | 26,4 | 6,7 | 3,9 | 2,28 | | 1,01 | | 0,32 | |
| T4 | 27,9 | 6,9 | 3,7 | 2,23 | | 1,43 | | 0,30 | |
| T5 | 29,1 | 7,1 | 3,5 | 2,33 | | 2,14 | | 0,34 | |

As can be seen from Table 1, the relative deviation did not exceed 4%, and the calculated adequacy criteria (Fisher, Student and Cochrane) are below the critical value, which confirms the adequacy of the experimental data.

**Conclusions**

The conducted experiment showed that the obtained results can be used to check the adequacy of the obtained experimental data. The experiment on heating small-sized elements of reinforced concrete columns at control points on heated and non-heated surfaces and at the level of reinforcement of wall fragments was carried out in accordance with the requirements of the standards for testing columns for fire resistance. The results obtained during the experiment are reliable.

Based on the results of this work, the following was established:

The stages of creation of 3 small fragments of reinforced concrete columns from heavy concrete with reinforcement are described. Overall dimensions: 200×200×998 mm, 200×200×999 mm and 200×200×998 mm. They were aged in a special room for at least 28 days.

The method of conducting an experiment on heating a small-sized element of a reinforced concrete column is described. Conducting the above-mentioned experiment in a small-sized installation to study the thermal effect of fire on building structures without mechanical load consists in the effect of the standard temperature regime of fire when heating an element of a reinforced concrete column from four sides. Thermocouples were used to measure the temperature in the furnace

TChA-2388 with a wire diameter of 1.25 mm, which can be used to measure temperatures in the range from 0 to 1300°C.

According to the conducted experiment, there is a uniform temperature distribution on the heated surface of the small-sized fragment under study, the maximum temperature reached on the surface was 709 °C, it was observed at the last minute of the experiment and continued to increase linearly after leaving the plateau. The maximum temperature in the center of the column was 105°C, it was observed at the last minute of the experiment and continued to increase linearly after leaving the plateau.

The adequacy of the experimental data was confirmed: the relative deviation did not exceed 4%, and the calculated adequacy criteria (Fisher, Student, and Cochrane) were below the critical value.

Taking into account the work and conclusions 1-4, it is advisable to conduct an experiment on heating a small-sized element of a reinforced concrete structure in a prototype of a compact fire installation at a standard temperature regime with a check of the adequacy of experimental data. The input data of the experimental study, on the basis of which it is possible to calculate the temperature field in the entire structure, solve the problem of strength and evaluate the fire resistance of large-sized structures, is a perspective for further research of this work.

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*Стаття надійшла 23.03.2024*

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**ДОСЛІДЖЕННЯ ТЕПЛОВОГО ВПЛИВУ ПОЖЕЖІ НА ФРАГМЕНТИ ЗАЛІЗОБЕТОННИХ КОЛОН ЗА РЕЗУЛЬТАТАМИ ЕКСПЕРИМЕНТАЛЬНИХ ВИПРОБУВАНЬ**

У роботі проаналізовано тепловий вплив пожежі на фрагменти залізобетонних колон на основі їхнього нагрівання за стандартним температурним режимом пожежі у малогабаритній установці для дослідження теплового впливу пожежі на будівельні конструкції. На основі запропонованого способу створено методику, яка дає можливість розрахунковим шляхом оцінити межу вогнестійкості повнорозмірної конструкції. Описано хід та результати проведеного вогневого випробування та перевірено адекватність та відтворюваність експериментальних даних. Проаналізовано розподіл температур по всій площі вогневої печі, досліджуваних фрагментів та оброблено отримані результати. Перевірено можливість створення у камері вогневої печі стандартного температурного режиму пожежі. За результатами даної роботи встановлено що, прогрів конструкції на всіх рівнях був рівномірним у площинах розміщення термопар, максимальна температура на поверхні склала 709°С, спостерігалась на останній хвилині експерименту та продовжувала лінійно зростати, максимальна досягнута температура у центрі колони скала 105°С, спостерігалась на останній хвилині експерименту та продовжувала лінійно зростати; Адекватність експериментальних даних підтверджено: відносне відхилення не перевищило 4%, а розраховані критерії адекватності (Фішера, Стьюдента та Кохрена) нижче за критичне значення.

**Ключові слова:** залізобетонна колона, випробування, малий фрагмент, компактна пожежна установка, експериментальне дослідження, температура, тест Фішера.

УДК 614.841

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*У роботі проаналізовано тепловий вплив пожежі на фрагменти залізобетонних колон на основі їхнього нагрівання за стандартним температурним режимом пожежі у малогабаритній установці для дослідження теплового впливу пожежі на будівельні конструкції.*

Табл. 1. Іл. 5. Бібліогр. 9 назв.

UDC 614.841
*Nuianzin O.M., Kozak A.A., Yanishevskyi V.E., Kryshtal V.M.* **Study of the thermal effect of fire on fragments of reinforced concrete columns based on the results of experimental tests /** Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2024. – Issue 112. – P. 202-208.
*The paper analyzes the thermal effect of fire on fragments of reinforced concrete columns based on their heating according to the standard fire temperature regime in a small-sized installation for the study of the thermal effect of fire on building structures.*
Tabl. 1. Fig. 5. Ref. 9.

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