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THE RESEARCH OF THE FIRE RESISTANCE LIMITS OF A REINFORCED CONCRETE SLAB ACCORDING TO THE RESULTS OF FIRE TESTS WITHOUT MECHANICAL LOAD

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The paper analyzes the thermal effect of fire on reinforced concrete slabs 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. On the basis of the proposed method, a methodology was created that makes it possible to obtain data on temperature distributions on the surfaces of a slab fragment and in its cross-section. 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 during the heating of reinforced concrete, the release of moisture and steam inside the material was observed: on the heated surface, this process took place from 15 to 25 minutes, on the unheated surface from 39 to 57 minutes, and at the level of the reinforcement from 31 to 55 minutes, the heating of the structure at all levels was uniform in the planes of placement of thermocouples, the maximum temperature at the level of the reinforcement was 200°C, it was observed in the last minute of the experiment and continued to increase linearly after leaving the plateau, the maximum temperature on the unheated surface of the rock was 110°C, it observed at the last minute of the experiment and continued to grow 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.

Key words: experimental results, small fragment, compact fire installation, reinforced concrete slab, temperature, reproducibility of experimental data.

Introduction. 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.

The development of scientific knowledge in the field of assessing the fire resistance of reinforced concrete structures and its process was and is being carried out by many scientists, in particular Yakovliev O.I., Roitman V.M., Kharchenko I.O., Bushev V.P., Milovanov O.F., Fomin S.L., Strakhov V.L., Pozdieiev S.V., Krukovskyi P.H., Novak S.V., T. Lie, B. Bartelemi, G. Kruppa, T. Harmathy, however, in their works, insufficient attention was paid to the creation of a universal experimental and calculation method for assessing the fire resistance of building structures, which can take into account the peculiarities of the construction of the building structure, the conditions of its further operation and ensure the accuracy of the calculation data. It is necessary to ensure a consensus between experiments and subsequent calculations. Therefore, the use of special portable means, which will simultaneously ensure the consideration of the features of the multi-composite material and the calculation method based on the obtained data, is relevant and will contribute to solving the problem of the effectiveness of tests for evaluating the fire resistance of reinforced concrete building structures in order to guarantee the necessary time for evacuation and conducting search and rescue operations.

1. Problem statement and method of its solving. There are European standards that are in force in Ukraine as well, regarding the assessment of fire resistance of reinforced concrete load-bearing structures, in particular slabs [1-3]. These normative documents define the possibility of carrying out tests without the use of load on samples of building structures, in particular slabs, 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.

The purpose of the work is to analyze the results of the temperature distributions of the thermal effect of fire on a small-sized element of a reinforced concrete slab during its heating in a compact fire furnace, with the conclusion of the possibility of their further application in assessing the fire resistance of a full-scale structure.

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

To describe the stages of creating small-sized fragments of reinforced concrete slabs for conducting 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 slabs.

To verify the experimental data obtained during the fire test.

To determine the prospects for further research.

2. Study methods. 3 Fragments without a hollow reinforced concrete slab with a nominal size of 1200×1200 mm and a thickness of 220 mm, which were manufactured in advance of the test.

Proportions for making fragments (per 1 m3): "500" brand Portland cement - 460± 10 kg; quartz sand - 660 ± 10 kg; crushed granite - 1150 ± 10 kg; water.

The reinforcement corresponded to the reinforcement actually used in the construction of slabs of modern residential buildings from monolithic reinforced concrete. Reinforcement - Vr-I class wire with a diameter of 5 mm.

Water-cement ratio: W/C = 0,36 × (water – 165 ± 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. Mixing of the concrete mixture was carried out in a free-falling concrete mixer 0,75 m^3. The compaction of the concrete mixture is performed by deep vibrators. The construction was made using standard collapsible formwork [10-11].

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

The samples were stored in a closed room, then transported to the place of testing and installed in a fire furnace (Fig. 1). The samples were in the formwork for seven days. After demolding, the fragment and auxiliary samples were stored for 28 days. After aging for 28 days, the fragments were stored in normal conditions of temperature and humidity until the beginning of the tests.

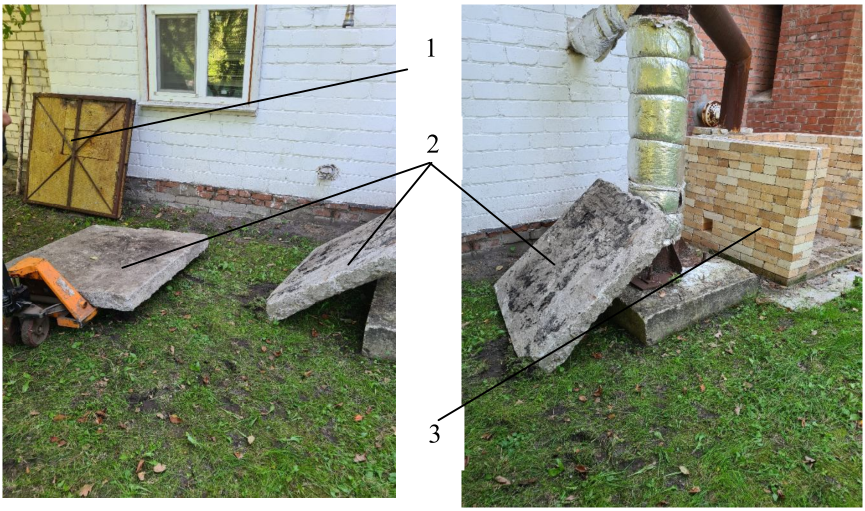

Fig. 1. A small-sized fragment of a reinforced concrete slab made in advance of the test: 1 – a cover for closing the fire furnace chamber; 2 – fragments of reinforced concrete walls for testing; 3 – installation for conducting tests

The general method of conducting tests in a compact fire furnace without mechanical load consists in the influence of the standard temperature regime of fire during one-sided heating of an element of a reinforced concrete slab, based on which, by calculation, it will be possible to estimate the limit of fire resistance of a full-sized structure.

Before the start of the test, the date of the study, ambient air temperature, air humidity, wind strength and direction were recorded. Before starting, the overall dimensions of the sample, the thickness of the sample are measured and the established data are recorded: 3 samples with a thickness of 220 mm were produced:

Sample 1: 1202 × 1198 mm.

Sample 2: 1197 × 1193 mm.

Sample 3: 1201 × 1199 mm.

The test sample is fixed in the upper part of the installation. The front wall of the installation is missing, so it is closed with a lid (Fig. 1). Mineral wool and lime cord were used for tightness. Fig. 2 shows the scheme of setting up the sample for testing.

When testing slabs, 2 burners are used. They are placed from the bottom of the installation on the opposite walls of the chamber diametrically, so that the flame torches located 80 cm from the test sample (Fig. 2). At the time of testing the slabs, places for burners that were not in use were covered with bricks and mineral wool to prevent the exit of furnace gases through these holes.

The measuring equipment used during the experiment on heating a small-sized element is listed in Table 1, and the location diagram is in Fig. 3.

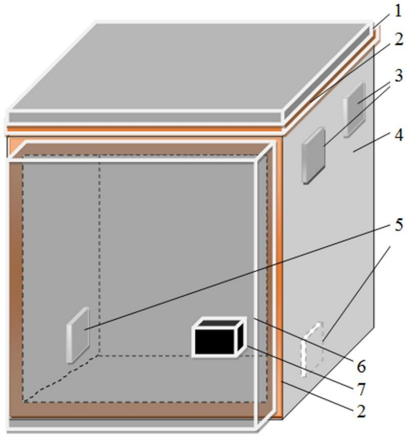

Fig. 2. Scheme of setting up a sample for testing: 1 – the sample under examination; 2 – mineral wool and lime cord sealant; 3 – places for burners not used during fire tests of walls; 4 – furnace enclosure; 5 – burners that create a temperature regime in the furnace chamber; 6 – the cover of the front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

Table 1

Means of measuring technology

The name of the equipment or device	Measuring range	Measurement error
Thermocouple THA-2388 with an ADC module (Cold-Junction Compensated Thermocouple-to-Digital Converter)	from -200 to +700 °C from +700 to +1350°C	± 2,0°C ± 4,0°C
Thermistor	from +5 to +300°C	± 1,0 %
Measuring ruler	from 0 to 1000 mm	± 1 mm
Stopwatch SOS pr-2b-2-000	from 0 s to 60 s from 0 s to 60 min	$\pm\left(\frac{0.4}{60}\tau\right)$ $\pm\left(0.4+\frac{1.5}{3540}(\tau-60)\right)$
Aspiration psychrometer MB-4M	from 10 to 100 % from – 10° to 50°C	± 4 % ± 0,2°C
Calipers ShTs-1	from 0 to 125 mm	± 0,1 mm
Aneroid barometer M67	600 - 800 of mercury column	± 1 mm of mercury column
Anemometer ACO-3	from 0,3 to 5 m/s	± (0,1+0,05V) m/s

Fig. 3 shows the location of thermocouples and division of the slab section into zones.

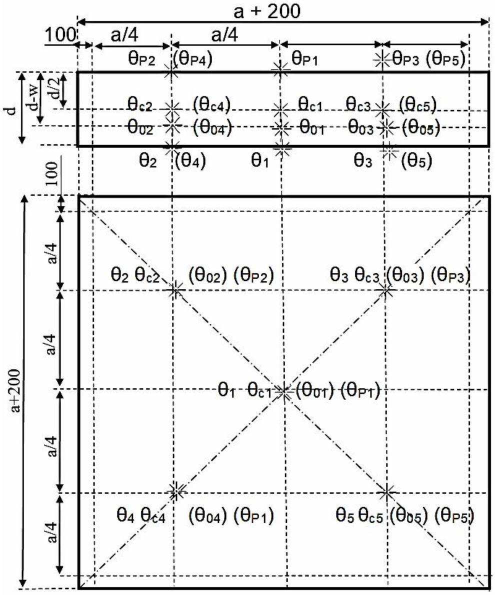

Fig. 3. Diagram of thermocouple location and division of the slab cross-section into zones

Thermocouples were used to measure the temperature in the furnace TXA-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 plugin for Microsoft Excel was used to process the received data, which allows you to see the numerical values of the temperature in real time and draw the corresponding graphs.

3. Presentation of the study basic material. During the tests, photo and video recording of the experiment was carried out (Fig. 4).

Fig. 4. A view of a fire furnace prepared for heating of a slab fragment

Fig. 5 shows the furnace chamber heating graphs according to the readings of each of the installed thermocouples.

As evidenced by the thermocouple heating data (Fig. 5), the linear heating rate of the furnace chamber corresponded to the "standard" fire temperature curve, and was within the limits defined by the standard

[1]. When the value of 980°C was reached, a stationary mode was established by adjusting the heating power of the furnace. The test lasted 63 minutes.

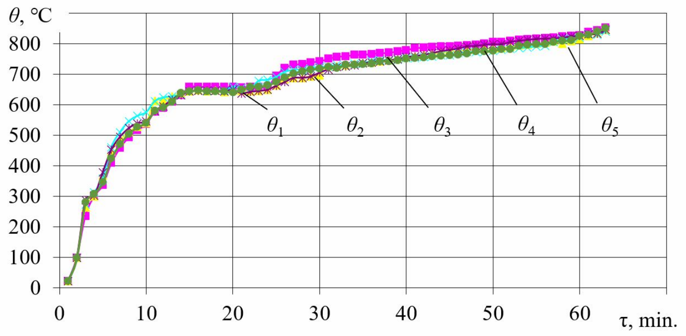

Fig. 5. The linear heating rate of the furnace chamber during the stove test

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

A visual inspection established that there was no loss of integrity, heat-insulating and load-bearing capacity of the sample.

Fig. 6-9 show the results of thermocouple readings on the heating, non-heating surface and at the level of the armature.

After analyzing the data obtained from the results of the experiments (Fig. 6-9), 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];
- during the heating of reinforced concrete, the release of moisture and steam inside the material was observed: on the heating surface, this process took place from 15 to 25 minutes (Fig. 6), from 39 to 57 minutes on the non-heating surface (Fig. 7), and at the level of the reinforcement from 31 up to 55 minutes (Fig. 8);
- heating of the structure at all levels was uniform in the planes of placement of thermocouples (Fig. 6-9);
- the maximum temperature at the level of the reinforcement was 200°C, observed in the last minute of the experiment and continued to increase linearly after leaving the plateau;
- the maximum temperature on the unheated surface of the rock was 110°C, it was observed at the last minute of the experiment and continued to increase linearly after leaving the plateau;
- it is necessary to verify the experimental data to confirm their validity;
- the obtained experimental data are sufficient for further calculation of temperature fields inside the structure and assessment of fire resistance of structures [12].

4. Verification. 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 a reinforced concrete slab made under similar conditions from identical materials.

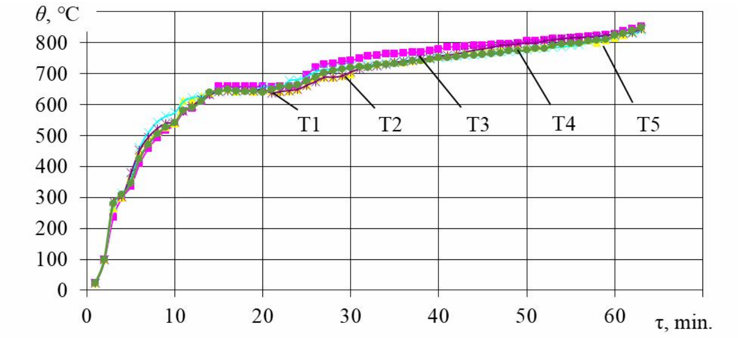

Fig. 6. The results of temperature measurement on the heating surface of the sample under study: θ1- θ5 – readings of thermocouples (Fig. 3)

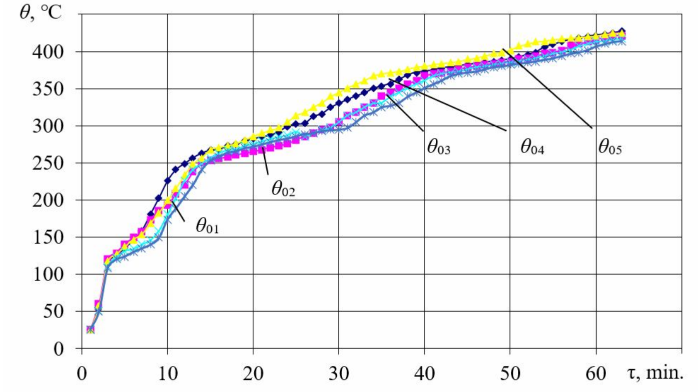

Fig. 7. The results of temperature measurement at the level of the armature of the sample under study: θ01- θ05 – readings of thermocouples (Fig. 3)

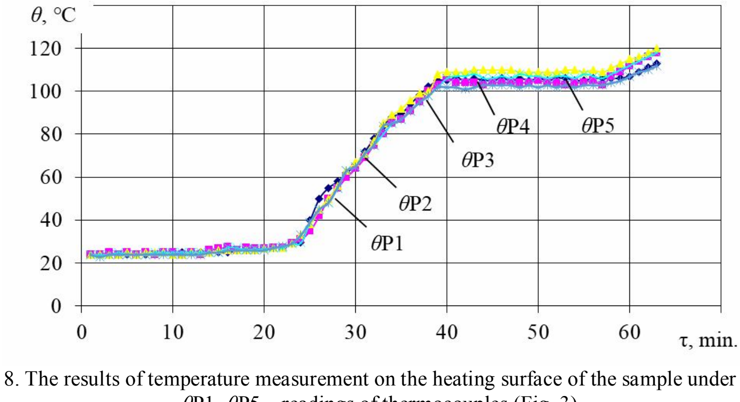

Fig. 8. The results of temperature measurement on the heating surface of the sample under study: θP1- θP5 – readings of thermocouples (Fig. 3)

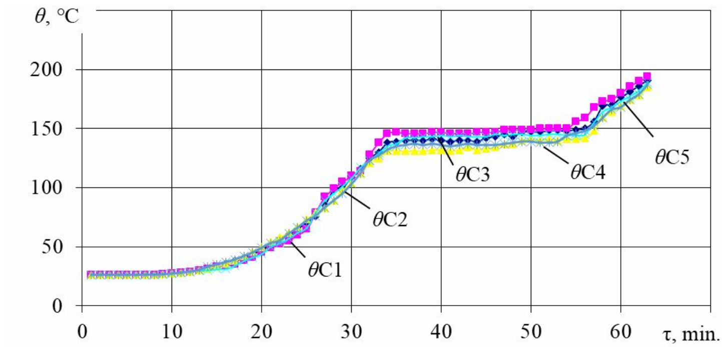

Fig. 9. The results of measuring the temperature on the thickness 110 mm (middle of the slab): TC1-TC5 – readings of thermocouples

To check the adequacy of the results of experimental data when heating wall fragments, the relative deviation was calculated, as well as the adequacy criteria (Fisher, Student and Cochrane).

The results of the calculation of the adequacy criteria are summarized in the table 2.

Table 2

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

Thermocouple zone (fig. 3)	Maximum deviation, °C	Average deviation, °C	Relative deviation, %	F-criterion	Critical value of F-crit.	t-criterion	Critical value of t-crit.	Q-criterion	Critical value of Q-crit.
T1	23,8	7,1	4,0	2,26		1,50		0,31	
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	
T01	5,8	3,1	2,9	1,38		1,21		0,33	
T02	6,4	2,8	3,2	1,43		1,81		0,32	
T03	6,2	2,5	2,9	1,29	4,49	1,50	2,92	0,31	0,45
T04	8,3	2,6	2,8	1,32		1,10		0,34	
T05	7,1	2,7	2,8	1,34		1,16		0,31	
TP1	5,2	2,3	2,3	1,19		1,41		0,25	
TP2	5,3	2,4	2,3	1,13		1,21		0,20	
TP3	5,6	2,5	2,4	1,14		1,48		0,21	
TP4	4,9	2,1	2,2	1,23		1,93		0,23	
TP5	5,2	2,4	2,3	1,16		1,53		0,21	

As it can be seen from the table. 2, the relative deviation did not exceed 8%, 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 leads to the conclusion 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 slabs at control points on heated and non-heated surfaces and at the level of reinforcement of slab fragments was carried out in accordance with the requirements of the standards for conducting fire resistance tests. The results obtained during the experiment are reliable.

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

1. The stages of creating 3 small fragments of reinforced concrete slabs from heavy concrete with reinforcement are described. Overall dimensions: 1202×1198 mm; 1197×1193 mm; 1201×1199 mm, 220 cm thick. They were aged in a special room for at least 28 days.
2. The method of conducting an experiment on heating a small-sized element of a reinforced concrete slab is described. Conducting the above-mentioned experiment in a small-sized installation for the study of 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 slab during one-sided thermal effect. TXA-2388 thermocouples with a wire diameter of 1.25 mm were used to measure the temperature in the furnace, which can be used to measure the temperature in the range from 0 to 1300°C. The MF 52 thermistor was used to measure the temperature in the tested sample, it can be used to measure the temperature in the range from -30 to 300°C.
3. According to the conducted experiment: during the heating of reinforced concrete, the release of moisture and steam inside the material was observed: on the heated surface, this process took place from 15 to 25 minutes, on the unheated surface from 39 to 57 minutes, and at the level of the reinforcement from 31 to 55 minutes, heating of the structure at all levels was uniform in the planes of placement of thermocouples, the maximum temperature at the reinforcement level was 200°C, it was observed at the last minute of the experiment and continued to increase linearly after leaving the plateau, the maximum temperature on the non-heating surface was 110°C, it was observed at the last minute of the experiment and continued to grow linearly after leaving the plateau.
4. 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.
5. 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 small-sized 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, to solve the problem of strength and to evaluate the fire resistance of large-sized structures, is a perspective for further research of this work.

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ДОСЛІДЖЕННЯ МЕЖІ ВОГНЕСТІЙКОСТІ ЗАЛІЗОБЕТОННОЇ ПЛИТИ ЗА РЕЗУЛЬТАТАМИ ВОГНЕВИХ ВИПРОБУВАНЬ БЕЗ МЕХАНІЧНОГО НАВАНТАЖЕННЯ

Актуальність. У дослідженнях сьогодення недостатньо уваги приділено створенню універсального експериментально-розрахункового методу оцінювання вогнестійкості будівельних конструкцій, що може врахувати як особливості виготовлення будівельної конструкції, умов її подальшої роботи та забезпечити точність розрахункових даних. Необхідно забезпечити консенсус між експериментами та подальшими розрахунками. Тому застосування спеціальних портативних засобів, що одночасно забезпечить врахування особливостей багатокомпозитного матеріалу та розрахункової методики на основі отриманих даних є актуальним і сприятиме вирішенню проблеми ефективності випробувань з оцінювання вогнестійкості залізобетонних будівельних конструкцій для гарантування необхідного часу евакуації та проведення пошуково-рятувальних робіт. **Мета роботи.** Метою роботи є аналіз результатів температурних розподілів теплового впливу пожежі на малогабаритний елемент залізобетонної плити під час її нагрівання у компактній вогневій печі з висновком можливості подальшого їхнього застосування при оцінці вогнестійкості повномасштабної конструкції. **Результати.** Проведений експеримент спонукає до висновку, що отримані результати, можливо застосовувати для перевірки адекватності отриманих експериментальних даних. Експеримент з нагрівання малогабаритних елементів залізобетонних плит у контрольних точках на обігрівній, не обігрівній поверхнях та на рівні арматури фрагментів плит проведений у відповідності до вимог стандартів щодо проведення випробувань на вогнестійкічсть на вогнестійкість. Результати, що отримані при проведенні експерименту є достовірними.

Ключові слова: експериментальні результати, малий фрагмент, компактна пожежна установка, залізобетонна плита, температура, відтворюваність експериментальних даних.

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Нуянзін О.М., Козак А.А., Костенко В.К., Кришталь М. А, Нуянзін В.М., Некора О.В. **Дослідження межі вогнестійкості залізобетонної плити за результатами вогневих випробувань без механічного навантаження** / Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 110. – С. 264-276. – Англ.
У роботі проаналізовано тепловий вплив пожежі на залізобетонні плити на основі їхнього нагрівання за стандартним температурним режимом пожежі у малогабаритній установці для дослідження теплового впливу пожежі на будівельні конструкції.
Табл. 2. Іл. 9. Бібліогр. 12 назв.

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Nuianzin O.M., Kozak A.A., Kostenko V.K., Kryshtal M.A., Nuianzin V.M., Nekora O.V. **The research of the fire resistance limits of a reinforced concrete slab according to the results of fire tests without mechanical load /** Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2023. – Issue 110. – P. 264-276.
The paper analyzes the thermal effect of fire on reinforced concrete slabs 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. 2. Fig. 9. Ref. 12.

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