Experimental and computer researches of ferroconcrete floor slabs at high-temperature influences

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Abstract. The unsatisfactory technical condition of many buildings and structures is due to their aging and requires a quick technical condition assessment. The most promising way for experimental researches data verification is computer modeling of structures, also during a fire. It is advisable to use the ANSYS software. Experimental fire tests of reinforced concrete slabs were carried out. In order to assess the experiment quality and the reliability of the received temperature distribution data, it was used a reinforced concrete slab computer simulation in the ANSYS R.17.1 software system. There was provided a comparative analysis of experimental studies results and numerical data analysis. The results confirm that method of conducted experimental research and computer simulation with further numerical analysis can be recommended for practical application. The mathematical model makes possible operative prediction for the controlled parameters values of building structures.

1 Introduction

The increase in the risk of man-made emergencies in Ukraine can be explained that recently, high-risk objects and potentially dangerous objects in the most important areas, have a project resource development of 50-70%, sometimes reaching emergency levels [1, 2].

The majority of emergencies arose due to the unsatisfactory technical condition of structures and equipment of engineering networks. Moreover because of their significant deterioration as a result of the normative term expiration, exploitation and exhaustion of normative resources, non-completion of regulatory volumes for planned preventive repairs, operating regulations violation and operation insufficient reliability in conditions of aggressive environment and extreme natural disasters [3].

Therefore, it is important to conduct surveys, assess the technical condition and restore the operational suitability of existing structures, as well as technical condition and possible destruction forecasting after the effects of high temperatures with the subsequent use of protective measures. At the same time, it is necessary to resolve issues related to the long and reliable building structures operation secure by adopting appropriate materials or protective measures, as well as the definition of the stress-strain state of structures with different influences and the execution of works on the exploitation extension of both individual structures and buildings in general.

There was a simulation of the study [4] of thermal properties of reinforced concrete structural elements provided. Thermal analysis was carried out numerically using the ABAQUS package. Results comparison of various research studies taking into consideration the influence of boundary conditions, like temperature, convection and radiation. The assignment of convective and radiation boundary conditions made it possible to obtain more accurate results. A decrease in the difference between simulated and experimental results was observed with the use of thermal characteristics according to Eurocode2, which took into account the moisture content.

The destruction of ferro-concrete columns after the influence of high temperatures under different temperature regimes was analyzed in another study [5]. When evaluating reliability, it is necessary to take into account the real temperature regime.

The article [6] investigates the state and prospects of the study of fire resistance of reinforced concrete columns. A complex analysis was provided on the limiting load-carrying capacity and mechanical behavior of columns during and after the operation of high temperatures. The statistical analysis was made to identify various factors of influence, including temperature, mode of fire, area and shape of cross-section, strength of concrete and aggregate state, axial load factor and eccentricity of load, longitudinal reinforcement, flexibility and conditions for fixing the edges of the column.

Study [7] generalized the engineering assessment study about temperature damage degree of reinforced concrete structures. The fire arose in part of the reinforced concrete structure and significantly damaged the supporting external wall. The purpose of analysis was to provide the wall condition quick assess and create necessary repairs or replacements recommendations. The engineering assessment of the damaged wall included a phase of non-destructive evaluation, which consisted of ultrasonic pulse rate testing and laboratory testing of the concrete samples removed from the damaged wall.

2 Unresolved issues

It is difficult to determine the damage of reinforced concrete structures during fire. The heterogeneous physical and mechanical properties of reinforced concrete at high temperatures in a result shows different temperature deformations, breaking the bonds between the individual components [8]. It is practically impossible to describe analytically the stress-strain state of reinforced concrete structures [9]. The results of experimental studies have a large scale of values and depend on many factors. Therefore, it is necessary to verify the data of the experiment. The most promising way is computer simulation of the design during a fire using the ANSYS software [10, 11].

The purpose of this study is to do the experimental research of multi-hollow reinforced concrete slabs thermal state at high temperatures and computer simulation of the process with subsequent comparison of results at control points.

3 Main part

The national standard DSTU B V.1.1-20:2007 [12] has been developed for tests conducting of overlapping and coatings elements for fire resistance in the Ukrainian Research Institute of Civil Protection. This standard is developed for the development of DSTU B V.1.1-4-98* [13], but it includes the features of these structures and their role in the construction of the house. The standard is intended to determine the reinforced concrete fire resistance, wood and composite ceilings and coatings, overlappings and coatings with glazed elements (for example, coverings with upper light windows), as well as overlays and coatings in which hanging ceilings are used, etc.

The essence of the test method is to determine the time interval from the beginning of the test under the temperature regime in accordance with DSTU B V.1.1-4-98* [13], when fire influence on the sample from below, before the achieving of boarding states of fire resistance conditions, which are regulated by this standard.

For experiments, it was used a fire furnace that meets the requirements of DSTU B V.1.1-4-98* [13] and provided a fire effect on a sample from below and had equipment for peeling and fixing the sample in the furnace and equipment for loading the sample (Fig. 1).

Fig. 1. A fire furnace for fire resistance of reinforced concrete structures research

The standard temperature regime is characterized by a standard temperature change curve, depending on the time for testing the structures for fire resistance, which is described by the formula [12, 13]:

$$\Theta g = 20 + 345 \log 10(8t + 1), \quad (1)$$

where is the

Θg - temperature of the environment, ºC;

t - hour, min;

20 - initial temperature, ºC.

Below are the results for fire resistance testing of two series (two pieces in each) multi-hollow pre-stressed reinforced concrete slabs without formwork formation PB 36-12-8 (3a). Both series of slabs were tested at the Testing Center LLC «Test» in Brovary city in accordance with the current normative documents requirements.

For first series tests there was used two samples of the plate PB 36-12-8 (reinforcement 3a) with sizes 3580×1195×220 mm. The bearing reinforcing frame consisted of four upper longitudinal pre-stressed reinforcing rods of reinforcement wire Ø5 BpII and seven lower groups of three reinforcing rods Ø5 BpII. Distribution armature of class A240C has a diameter of 10 mm. The thickness of concrete protective layer to the axis of the lower armature was 20 mm. The strength of concrete was C25/30 class.

In addition, auxiliary samples (cubes, prisms, fragments of reinforcing rods) were made. Tests of auxiliary samples allowed to obtain data about physical and mechanical characteristics of the materials that were used. Auxiliary samples (standard cubes and prisms) were concreted simultaneously with the main ones in the metal inventory formwork and stored under a layer of wet sawdust next to the slabs. Sections of reinforcing rods were removed from the reinforcement that were used to reinforce the slabs.

The samples were mounted on a horizontal oven with a 100 mm bolt on the edges through a layer of ROCKMIN basalt plates (thickness 100 mm, density 30 kg/m^3). The edges of the plates were not blocked, and the bottom surface was not lined with putty. The shape of the samples on the furnace under load is shown in Fig. 2

Fig. 2. Appearance of samples on the furnace under load

On each sample from the non-heating side of the ceiling slabs were installed 5 thermocouples THA, as shown in Fig. 3 [14, 15].

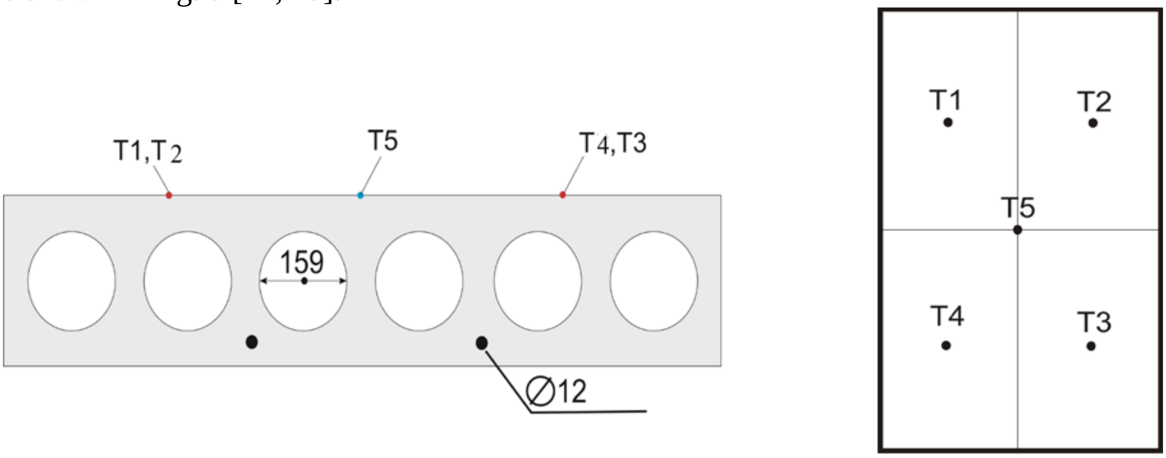

Fig. 3. Scheme of THA thermocouple location on non-heating surface

The tests were done on a horizontal test fire furnace.

During 25 min. tests there was noticed the formation of longitudinal cracks on both sides in the samples. Those cracks increased and on 39 minut of the test, there was a collapse (loss of integrity and bearing capacity) at the edge of sample number 2 (Fig. 4).

The test was extended to 45 minutes. Loss of load-bearing capacity, integrity and heat-insulating ability of sample No. 1 did not occur.

The maximum values of deflection and the rate of growth of deformations were (45 min), accordinly, 30 mm and 1 mm/min. (sample number 1) and 31 mm and 1 mm/min. (sample number 2).

According to the results of the tests, it was shown that the limit of fire resistance of slabs without overlooking the ends and facing with a putty is 38 minutes (REI 30).

As is known, most buildings for which multi-hollow floor slabs are made, belong to the I or II degree of fire resistance [16]. According to [16], the ceiling fire resistance of these structures should not be lower than REI 60.

Fig. 4. Area of collapse of sample number 2

To evaluate the results of experimental studies of the strained-deformed state of reinforced concrete slab at temperatures corresponding to the fire, a computer simulation of the process was performed with subsequent comparison of the results at the control points.

All these data were used in computer simulation of the slab in the ANSYS R17.1 software system (Figure 5).

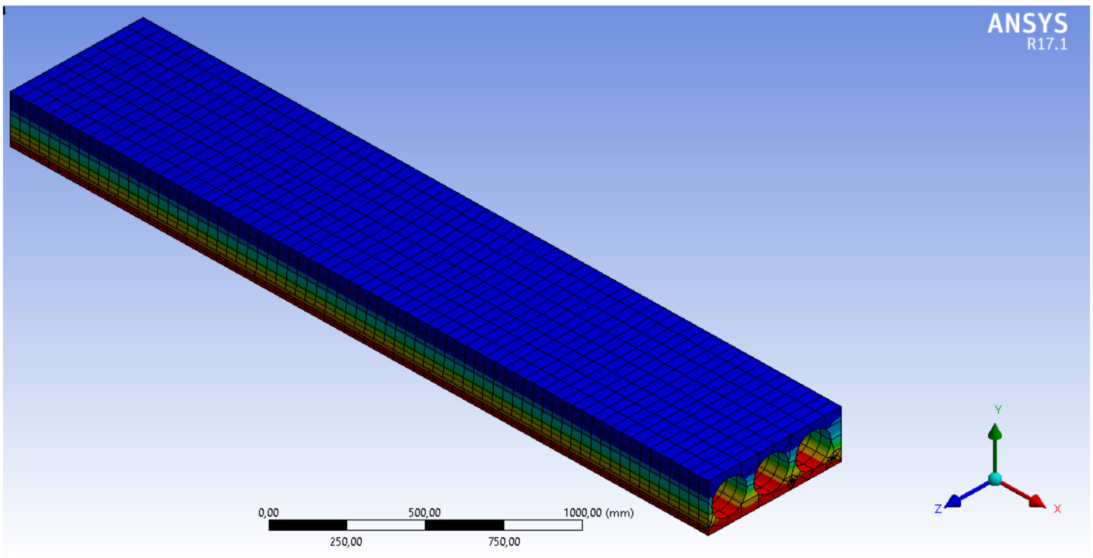

Fig. 5 Temperature distribution in the floor slab

During experiments, temperature changes were recorded at control points every minute. However, given the large amount of data in Table 1 shows only the results recorded in 5 minutes increments. For comparison, similar data extracted from the calculation results file in the ANSYS program (Table 1).

Table 1. Comparison of experimental and numerical results

Time, [min]	$T_{(1-4), cp}$, [ºC]	ANSYS, [ºC]	Error, [%]	T_5, [ºC]	ANSYS, [ºC]	Error, [%]
0	17	20	15,0	18	20	10,0
5	17	20	15,0	18	21	14,3
10	18	21	14,3	18	21	14,3
15	19	22	13,6	19	22	13,6
20	25	27	7,4	26	28	7,1
25	38	41	7,3	39	42	7,1
30	49	53	7,5	50	54	7,4
35	53	57	7,1	57	62	8,1
40	54	59	8,5	60	66	9,1
45	57	62	8,1	63	69	8,7
50	65	71	8,4	68	75	9,3

Table analysis 1 shows that the results of experimental research and numerical analysis in the ANSYS program for the first 15 minutes are quite different at all control points, however, this difference is subsequently stabilized, and until the end of the experiment does not exceed 10.0%, which can be considered acceptable.

4 Conclusion

Methods of conducting fire tests of slab constructions and building fragments have been improved. For fire resistance of structures evaluation with experimental methods it is possible to use two approaches: the consideration of the behavior of constructions in the real fire conditions (the fragment of a building at the actual fire load) and in a conditional fire (the evaluation of the fire resistance of a separate structure in the standard temperature regime in the test kiln).

Testing of constructions in conditions of conditional fire is regulated by the current normative documents and allows to perform tests with the further conclusions about sufficient fire resistance. In the conditions of insufficient fire resistance of separate constructions, it is necessary to develop additional measures for the protection of structures against the effects of high temperatures.

It was established that the ceiling slabs given for the test, without demining the ends (as required by the installation technology), and in the absence of the plaster putty facing the lower surface of the slab, had a fire resistance line of REI 30. It was concluded that the use of such slabs in buildings and structures I or II the degree of fire resistance is impossible without the necessary measures to increase the fire resistance (for example, the use of fire protection).

The values of the temperatures obtained in ANSYS for the plate points corresponding to the location of the T1 - T5 thermocouples are also slightly higher than the results of the experiment in all cases.

The results of experimental studies and numerical analysis in the ANSYS program for the first 15 minutes are quite different at all checkpoints, however, this difference is subsequently stabilized, and until the end of the experiment does not exceed 10.0%, which can be considered acceptable.

In general, the obtained results confirm that the technique of conducted experimental research and computer simulation with further numerical analysis can be recommended for practical application.

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