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Investigation of the regularities of temperature regime of fire in cable tunnels depending on its parameters

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Abstract. Simulation, as a method of scientific research, makes it possible, without performing costly and labor-intensive field experiments on models, to carry out all necessary experiments to determine the temperature modes of fire in cable tunnels. The purpose of the research of this work was to determine the temperature regime of fire in a cable tunnel depending on its shape, size and fire load. Mathematical models of cable tunnels were created in one of the CFD software systems. Cable products are constantly evolving and improving. For tests on the fire resistance of building structures of cable tunnels, a standard temperature mode of fire is used which may not correspond to fire mode in a real cable tunnel. The computational experiments were carried out and the temperature regimes of fires in tunnels with different parameters were determined. The obtained results showed the parameters of cable tunnels, which influence the temperature regime of fire in tunnels most. In this paper the use of computational experiments for the study of heat and mass transfer processes in fires in cable tunnels was examined further. CFD Fire Dynamics Simulator 6.2 was used.

1 Problem statement

Despite significant advances in solving problems to improve fire safety of cables now there are also many issues concerning both cables and cable lines, including cable tunnels of a rectangular cross section [1].

Cable products are constantly evolving and improving. For tests on the fire resistance of building structures of cable tunnels, a standard temperature mode of fire is used which may not correspond to fire mode in a real cable tunnel.

Simulation, as a method of scientific research, makes it possible to carry out all necessary experiments to determine the temperature modes of fire in cable tunnels without performing costly and labor-intensive field experiments on models. The computational experiments were carried out and the temperature regimes of fires in tunnels with different

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parameters were determined. The obtained results showed the parameters of cable tunnels which influence the temperature regime of fire in tunnels most.

2 Analysis of recent achievements and publications

In the works [2-4], studies on the development and spread of dangerous fire factors in cable structures were carried out. The behavior of building structures in case of fire was also examined. The conclusions were made on the basis of real and computational experiments.

In work [5] it was established that the rate of burnout of a fire load almost does not depend on the width of the tunnel. The natural experiments carried out in work [6] describe the distribution of temperature in tunnels with different aerodynamic parameters. The causes of fires in tunnels are analyzed in work [7]. In work [8], it was analyzed which parameters influence the rate of burnout of cable isolation. Analyzed The affect of the method of laying cables on the linear speed of the spread of fire. Despite the practical significance of such results, it is necessary to remember that cable products and construction constructions of cable tunnels are constantly being improved, therefore, additional ones need to be made. In previous studies [1, 9], we carried out natural experiments and verified established mathematical models. The obtained data made it possible to confirm the adequacy of computer models of fires in cable tunnels and to conduct mathematical modeling to determine the temperature regime of a fire for testing fire resistance of building structures of cable tunnels.

3 Purpose

The purpose is to study the patterns of temperature regime of fire in cable tunnels, depending on its geometrical, aerodynamic parameters and fire load as a scientific basis for calculating the limit of fire resistance of building structures of cable tunnels.

To achieve the goal, the following tasks must be solved:

1. To create mathematical models of cable tunnels with different geometric, aerodynamic parameters and fire load.
2. To carry out computational experiments of heat and mass transfer during a fire in the created mathematical models and to allocate the parameters of the tunnel which most significantly affect the temperature regime of the fire.
3. To construct the dependence of temperature modes of fire on time in cable tunnels depending on its geometric, aerodynamic parameters and fire load.

4 Method

Theoretical studies were carried out on the basis of systems of differential equations of continuous media of the type of Navier-Stokes equations and Fourier thermal conductivity equations. To solve the equations in the work, the method of finite or boundary elements, non-relation methods, Galerkin method, and optimization methods are used. Computational experiments for the study of heat and mass transfer processes during fire in cable tunnels were carried out in the CFD Fire Dynamics Simulator 6.2.

5 Consideration on methods and results

For the computing experiments 8 mathematical models of cable tunnels were created. For the tests, the following sequence of settlement procedures is used.

1. The CAD software creates a geometric configuration of the cable tunnel of the required size. Transverse dimensions of the tunnel varied. The height is 1.8 m to 2.2 m, the width is 1.6 m to 2.0 m. The length of the tunnel is always 10 m. The models of cables, steel angel bars, openings for the output of combustion products are created inside, and the horizontal component of the speed of movement of air is set. The geometric model is imported into the environment of the FDS settlement system.

2. The initial parameters of the simulation are introduced, which are impossible to change during the calculation: the initial ambient temperature, the air support on one side of the tunnel, the required time of fire (35 minutes).

3. A combustion process in the middle of the tunnel with a focus on the bottom line of the cable is initiated.

4. During the calculation, the temperature monitoring of the corresponding points in the tunnel and the temperature gradient is monitored online..

In order to control the temperature regime, by means of the FDS computer system 45 monitoring points were created (Figures 1-3). The places of temperature control were created according to the following principle:

1) in the plane of the cross-section of the inflammation zone there is 1 place of control in the geometric center and 4 more places in the geometric centers of the formed quaternion (Fig. 1).

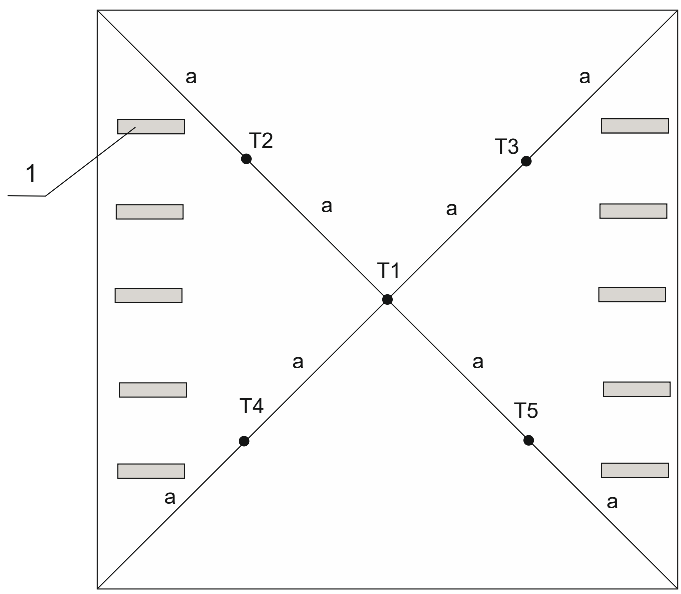

Fig. 1: The scheme of location of control points of temperature in the geometric section of the cable tunnel: 1 - cable line, T1 - T5 – the places of temperature control, a - geometrical dimension parameter depending on the cross section of the tunnel.

2) 10 planes were created, 5 control points in each: 2 planes at a distance of 0.5 m from the fire cell in different directions. Also, at a distance of 2, 4, 6 m. The general layout of the planes is shown in Fig. 2.

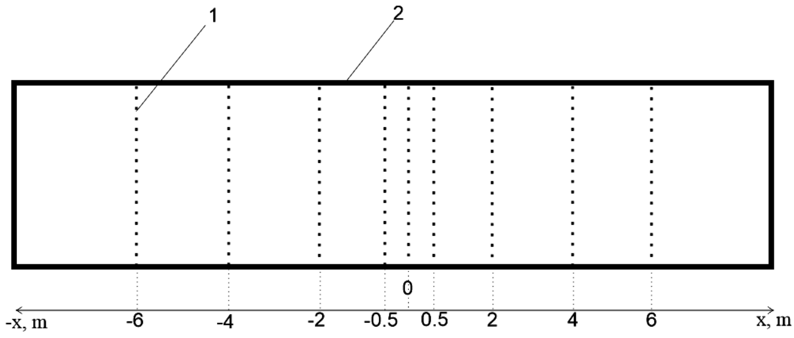

Fig. 2: The layout of the planes in which there were places of temperature control along the length of the cable tunnel: 1 - a plane in which there are 5 temperature control points in the manner shown in Fig. 4, 2 - fencing of a cable tunnel.

The general view of a cable tunnel with places for temperature control is shown in Fig. 3.

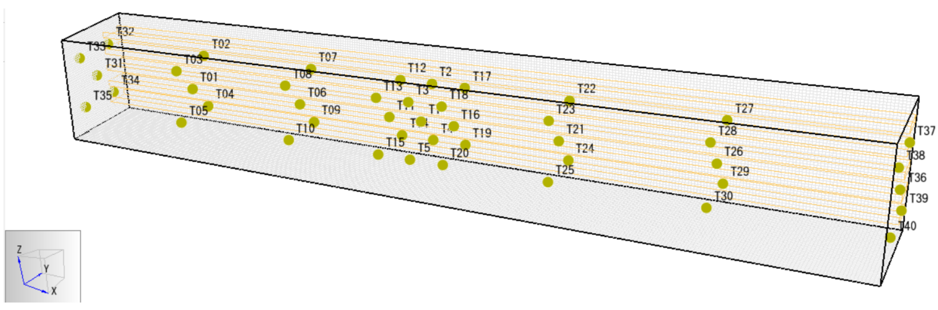

Fig. 3: General View of a Cable Tunnel with Places of Temperature Control: T01 - T40, T1 - T5 - places of control.

The scheme of the tunnel with geometric parameters which were changed is shown in Fig. 4.

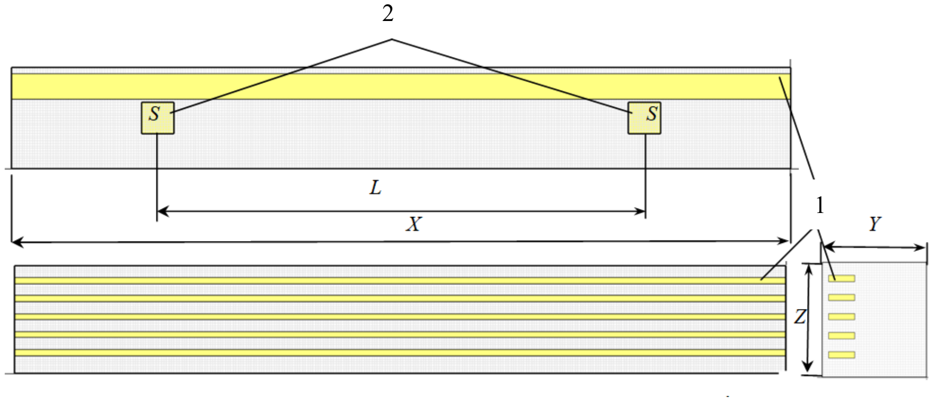

Fig. 4: The scheme of the tunnel with changed geometric parameters: 1 - model of cable lines; 2 - model of ventilation and inspection hatches with the area *S*, m^2; *X, Y, Z, L* –distance between the holes.

In accordance with the calculation scheme of the mathematical model of the tunnel (Fig. 3) for the purpose of conducting a complete analysis of the parameters influencing the temperature regime of the fire the following parameters varied:

1. Fire load:

- cable lines were modeled on two and one side;
- the number of cable lines is from 1 to 10;
- the material of isolation of cables and conductors has changed. Due to this, the speed of thermal energy output from 1 m^2 of cable lines changed (Table 1).

2. Geometric parameters of the cable tunnel:

- varied as a cross-sectional area, using a combination of parameters *Y* and *Z*, the general parameter is the cross-sectional area of the cable tunnel (Table 1).

3. Aerodynamic parameters:

- the horizontal component of the speed of air was set as a parameter that characterizes the excess or lack of oxidants and influences the intensity of the development and spread of the fire.

To construct a mathematical model of the temperature regime of a fire in a cable tunnel, it is necessary to conduct a complete factor computing experiment. In this case, there are three independent factors - the cross-sectional area of the cable tunnel, the fire load, as well as the horizontal component of the air flow inside the tunnel. In table. 1 there are intervals of the parameters in the experiment, which are selected as factors.

Table 1. Intervals of variation of factors in a computational experiment.

Parameter	Minimum value	Average value	Maximum value
Fire load (speed of thermal energy output from 1 m^2 of cable lines), kW/m^2	749	4120	7490
Cross-sectional area of the cable tunnel, m^2	2.88	3.64	4.4
The horizontal component of air velocity, m/s	0	2.5	5

8 computational experiments were conducted to determine the parameters that have the most significant effect on the temperature regime of the fire. A typical matrix for planning a complete factor experiment for determining the temperature regime of a fire in a tunnel is shown in Table 2.

Table 2. A typical matrix for planning a complete factor experiment for determining the temperature regime of a fire in a tunnel.

№	x1	x2	x3	x1x2	x1x3	x2x3	x1x2x3
1	+	+	+	+	+	+	+
2	-	+	+	-	-	+	-
3	+	-	+	-	+	-	-
4	-	-	+	+	-	-	+
5	+	+	-	+	-	-	-
6	-	+	-	-	+	-	+
7	+	-	-	-	-	+	+
8	-	-	-	-	-	-	-

The results of full factorial experimental determination of temperature control of fire in the tunnel are presented further. The order number of the computing experiment meets the conditions of the line from Table 2 and the conditions that were scheduled in Table 1.

After the completion of computational experiments, the temperature-time dependence data were obtained and processed.

According to the results of the mathematical modeling of heat and mass transfer during a fire in cable tunnels of various geometric sizes, fire loads and aerodynamic characteristics, corresponding to [10], the temperature regimes of the fire were calculated and shown in Fig. 5.

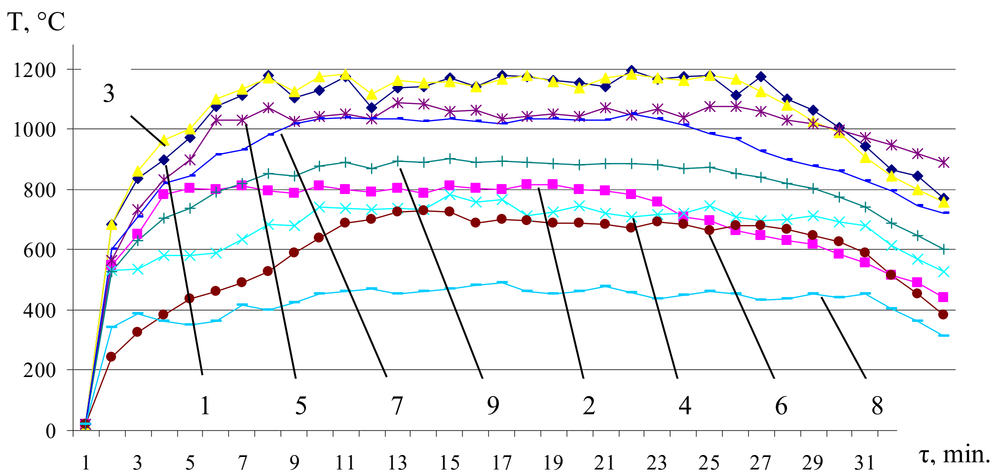

Fig. 5: The results of a full factor experiment for determining the temperature regime of a fire in a tunnel: 1-8 correspond to the matrix of planning (Table 2); 9 is the average value of computational experiments 1-8.

Analyzing the obtained graphs (Fig. 5) it can be stated that the fire load of the tunnel is influenced most by the temperature regime of the fire. At its maximum, the temperature reached 1200 °C, with a minimum of 500 °C. With an average level of fire load and variation of the remaining parameters, the maximum temperature inside the tunnel reaches 700-800 °C.

At the first stage (5-9 minutes), the temperature in the tunnel section rise to the maximum. At the second stage, within 25-30 minutes, the maximum temperature in the tunnel section is maintained. At the third stage there is a gradual cooling in the selected section of the cable tunnel.

6. Conclusions

As a result of researches of this work the regularities of the temperature regime of a fire in cable tunnels depending on its geometrical, aerodynamic parameters and fire loading as a scientific basis of calculation of the limit of fire resistance of building structures of cable tunnels are studied.

Thus, to test the building designs of cable tunnels for fire resistance, it is necessary to choose the most severe temperature regime, which differs from the standard [1]. According to mathematical modeling, the highest temperature is observed in the area of combustion. It is within 1200 °C with the maximum possible fire load in accordance with [10] (Fig. 5). However, if the parameters and the fire load of the tunnel are known, it may be possible to use a less intense test mode. However, in this case, it will be impossible to add cable lines or to change the design of the tunnel, as this can increase the fire load and change the temperature mode of the fire.

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