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JURISPRUDENCE

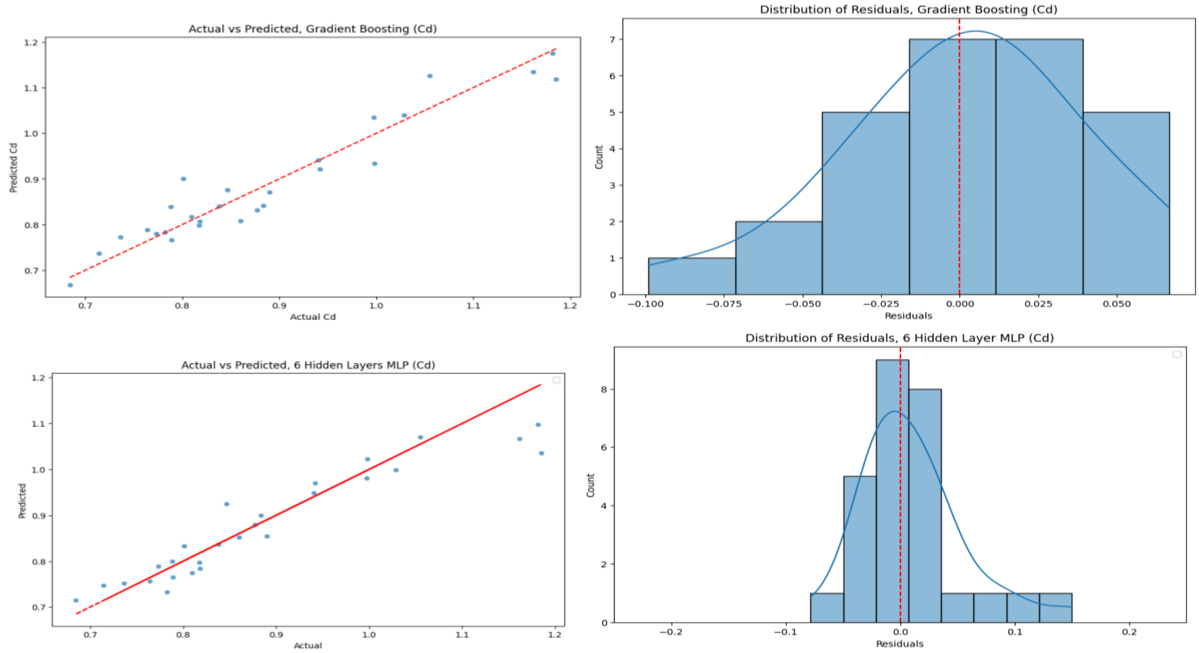

Рис. 3. график соответствия фактических и предсказанных значений и гистограмма распределения остатков Cd для Gradient Boosting и MLP с 6 скрытыми слоями

Результаты показали, что модели Gradient Boosting и Random Forest достигают высокой точности при прогнозировании коэффициентов C_d и C_m, с максимальным R^2=0.9211 и R^2=0.9448 соответственно. MLP также продемонстрировала стабильные результаты: для C_d R^2=0.8853 при MLP с 6 скрытыми слоями и для C_m R^2=0.8193 при MLP с 2 скрытыми слоями. Gradient Boosting показала ступенчатый характер предсказаний, тогда как MLP обеспечила плавную аппроксимацию, что подчеркивает важность выбора модели в зависимости от задачи и структуры данных.

В исследовании проведён сравнительный анализ традиционных и нейросетевых подходов, выявивший их сильные и слабые стороны. Результаты показывают, что модели каждого типа обладают уникальными преимуществами и ограничениями, что указывает на необходимость применения комбинированных подходов для объединения их результатов. Это открывает новые возможности для повышения точности прогнозов ветрового воздействия на высотные здания и решения других инженерных задач в строительстве, особенно при работе с ограниченными данными.

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STUDY OF TEMPERATURE CONDITIONS DURING FIRES IN CABLE TUNNELS

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ДОСЛІДЖЕННЯ ТЕМПЕРАТУРНИХ РЕЖИМІВ ПІД ЧАС ПОЖЕЖ У КАБЕЛЬНИХ ТУНЕЛЯХ

Abstract

The aim of this study is to determine the temperature regime of a 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 packages. Computational experiments were carried out and the temperature regimes of fires in tunnels with different parameters were determined.

The temperature regimes of fires in cable tunnels with different sizes, aerodynamic parameters and fire loads were determined, as well as the dependence of the fire temperature regime on these parameters. With 10 laid cable lines and a fire load of 2000 MJ/m2 , the maximum temperature exceeded 1200 ℃, with 1 line and a fire load of 688 MJ/m2 - 500 ℃.

With the smallest cross-sectional area of the tunnel and reduced airflow velocities, the temperature inside rises 50% faster than average. In addition, an excess of fresh air reduces the combustion temperature by 50-70°C, although it also contributes to the faster spread of fire along the cable lines.

In this work, the use of computational experiments to study the processes of heat and mass transfer during fires in cable tunnels was further developed.

Анотація

Метою проведення досліджень даної роботи є визначення температурного режиму пожежі у кабельному тунелі залежно від його форми, розмірів та пожежного навантаження. У одному з програмних комплексів CFD були створені математичні моделі кабельних тунелів. Проведено обчислювальні експерименти та визначено температурні режими пожеж у тунелях з різними параметрами.

Було визначено температурні режими пожеж у кабельних тунелях з різними розмірами, аеродинамічними показниками та пожежним навантаженням, а також залежність температурного режиму пожежі від зазначених параметрів. При 10 прокладених кабельних лініях та пожежному навантаженні 2000 МДж/м^2 максимальна температура перевищувала 1200 ℃, при 1 лінії та пожежному навантаженні 688 МДж/м^2 – 500 ℃.

При найменшій площі поперечного перерізу тунелю та зменшенні швидкостей повітряних потоків температура всередині зростає на 50 % швидше, у порівнянні з середніми параметрами. Крім того, надлишок свіжого повітря знижує температуру горіння на 50-70 ℃, хоч а і сприяє швидшому розповсюдженню пожежі вздовж кабельних ліній.

У даній роботі дістало подальшого розвитку застосування обчислювальних експериментів для дослідження процесів тепломасообміну під час пожеж у кабельних тунелях.

Keywords: *mathematical model, electrical networks, excessive heating, cable, fire, temperature regime.*
Ключові слова: *математична модель, електричні мережі, надмірний нагрів, кабель, пожежа, температурний режим.*

Problem statement.

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

The study of the fire temperature regime is a relevant issue, as cable tunnels differ in geometric configuration, type of cables laid in them, fire load and aerodynamic characteristics. This can lead to the fact that the fire temperature conditions in such tunnels may differ from the standard and from each other. In this case, it is impossible to guarantee that the fire resistance limits of the tested structures comply with the applicable standards. In this case, the safety of people and material assets during fires in cable tunnels may be significantly reduced.

Analysis of the latest research and publications.

In recent years, both experimental tests and numerical modelling have become more widely used [3-8]. In particular, these methods are used to study the parameters of fires in cable tunnels.

Ukrainian researchers often cite [3], which proposes a temperature regime for fire in tunnels. However, the dependence of temperature on fire load and geometric dimensions of the tunnel is not taken into account, and aerodynamic parameters are averaged.

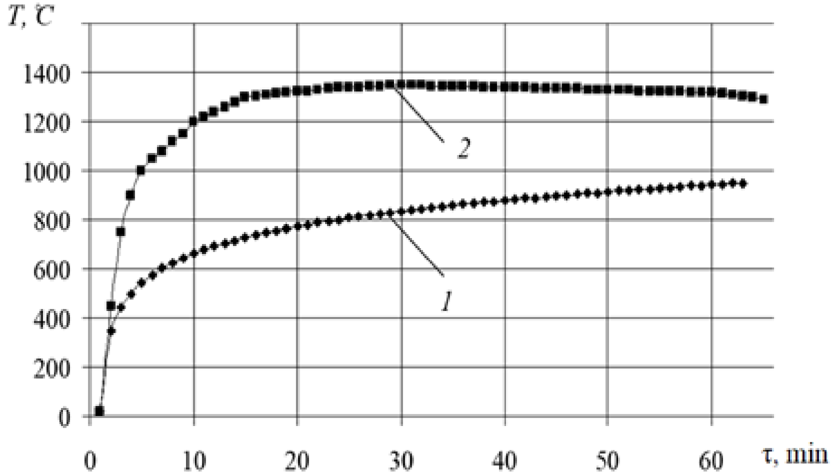

Figure 1. Fire temperature conditions: 1 - standard fire temperature regime [2]; 2 - fire regime in tunnels in accordance with [3].

Paper [4] describes the process of building mathematical models of heat and mass transfer in cable tunnels. Attention is focused on the construction of a grid for calculation, and an algorithm for creating such models is proposed.

Paper [5] conducted field tests in a cable tunnel. A fire was modelled with the initiation of combustion by a flammable liquid and subsequent burning of cables. This work provided data that could be used to verify mathematical models.

In [6], the adequacy of mathematical models was tested on the basis of experimental data from [5]. To this end, the adequacy criteria (Student's T-test, Cochran's Q-test, Fisher's F-test) and the relative error of the calculated data from the experimental data were calculated. The effectiveness of modelling thermal processes for further studies of fire temperature conditions in cable tunnels has been proven. According to [7], the dispersion of temperatures during a fire affects the fire resistance limit of building structures. Paper [8] analyses the metrological support of field experiments. This makes it possible to choose the right measuring equipment.

The research carried out in this scientific article is aimed at creating mathematical models of the cable tunnel, in which computational experiments were carried out. Computer modelling has been chosen as a tool that has advantages over full-scale research in terms of environmental friendliness, economy and efficiency. By confirming the adequacy of the computer modelling results with verification data [6], it became possible to study the temperature regimes of fires in cable tunnels of different sizes and with different fire loads.

According to previous studies [3-8], the variety of design features of cable tunnels, their fire load, gas inflow and outflow, and other parameters causes significant differences in fire temperature conditions. In particular, modern insulation of cable products may differ in fire performance from that studied by scientists [3-8].

This paper investigates the temperature conditions of fire in cable tunnels depending on the size, aerodynamic characteristics and fire load.

Formulation of the purpose of the article. To determine the temperature regime of a fire in cable tunnels with different sizes, aerodynamic characteristics and fire load, as well as the dependence of the temperature regime of a fire on these parameters. To do this, we will perform mathematical modelling of heat and mass transfer during a fire in cable tunnels in the FDS software package and analyse the results.

To achieve this goal, we need to solve the following **tasks**:

- to develop mathematical (computer) models of cable tunnels using CFD software systems and conduct computational experiments to assess the temperature conditions of fires in cable tunnels with different parameters.
- to determine the temperature regimes of fires in cable tunnels with different sizes, aerodynamic parameters and fire load, as well as the dependence of the temperature regime of the fire on these parameters.
- to analyse the results and outline the prospects for further research.

Presentation of the main material.

To conduct the computational experiment, a mathematical model of the cable tunnel is created. The following sequence of calculation procedures is used:

1. Using a CAD program, a geometric configuration of the cable tunnel of the required dimensions is created. Inside, models of cables, steel corners, a hole for the exit of combustion products and

a place for air supply are created. The geometric model is imported into the FDS calculation environment [4].

2. Initial modelling parameters that cannot be changed during the calculation process are entered:initial temperature of the medium, air pressure on one side of the tunnel, required fire time (35 minutes) [5].

3. The combustion process is initiated in the middle part of the tunnel directly on the cables.

4. After the calculation, the temperature and time curves of the fire in the direct burning zone of the cable tunnel and the temperature gradient are analysed.

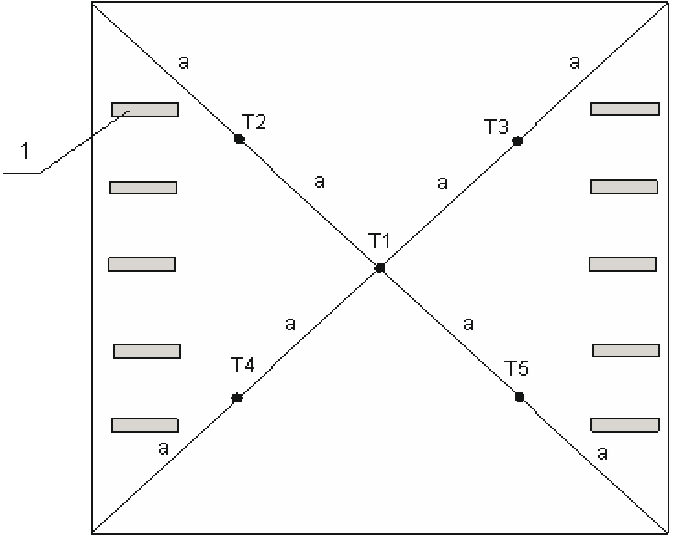

Figure 2. Schematic of the location of temperature control points in the geometric cross-section of a cable tunnel: 1 - cable line, T1 - T5 - temperature control points, a - geometric size parameter depending on the cross-section of the tunnel.

To control the temperature regime, 45 temperature control points were created using the FDS computer system (Fig. 4). Temperature control points were created according to the following principle:

1) in the plane of the cross-section of the inflammation zone, 1 control site in the geometric centre and 4 more sites in the geometric centres of the formed quarters (Fig. 2).

2) 10 planes were created, 5 control points in each: 2 planes at a distance of 0.5 m from the fire centre in different directions. Also at a distance of 2, 4, 6 m. The general layout of the planes is shown in Fig. 3.

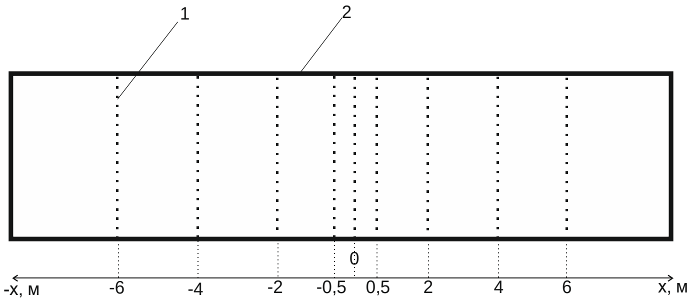

Fig. 3. Diagram of the location of the planes in which the temperature monitoring points were placed along the length of the cable tunnel: 1 - the plane in which 5 temperature control points are located in the manner shown in Fig. 4, 2 - cable tunnel enclosure.

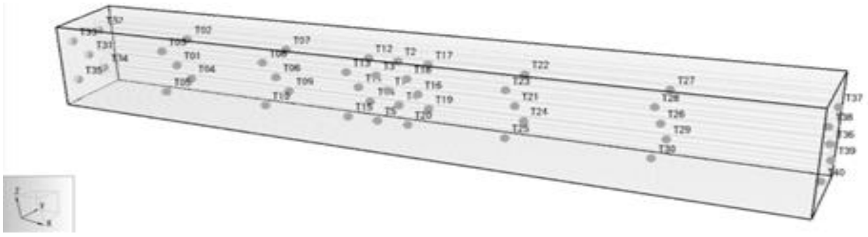

Figure 4. General view of the cable tunnel with temperature control points: T01 - T40, T1 - T5 - control points.

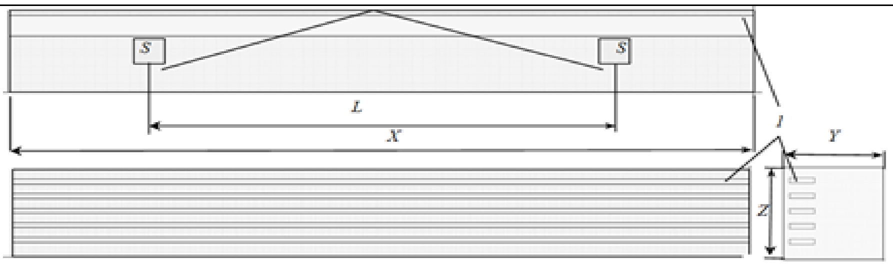

Fig. 5. Schematic of the tunnel with geometric parameters that changed: 1 - model of cable lines; 2 - model of ventilation and inspection hatches with area S, m2 ; X, Y, Z, L1 - distance between openings, m.

In accordance with the calculation scheme of the mathematical model of the tunnel (Fig. 5), the following parameters were varied in order to conduct a full analysis of the parameters affecting the temperature regime of the fire:

1. Fire load:

cable lines were modelled from two and one sides;

number of cable lines from 1 to 10;

the insulation material of cables and wire cores changed. This changes the amount of heat energy released from 1 m of2 cable.

2. Aerodynamic parameters:

The area of the openings of the ventilation and inspection hatches "S" varied from 0.3 to 0.5 m^2 ;

distance between the holes L;

location of cable lines;

3. Geometric parameters of the cable tunnel:

was varied as a cross-sectional area using a combination of Y and Z parameters;

the location of the fire;

parameter X depending on the location of the fire centre.

The next stage was to create a mesh cable tunnel. The method of control volumes used in the software package has certain peculiarities. There is a directly proportional relationship between the calculation accuracy and the number of calculation cells, and an inversely proportional relationship between the number of cells and the time it takes to perform the calculation.

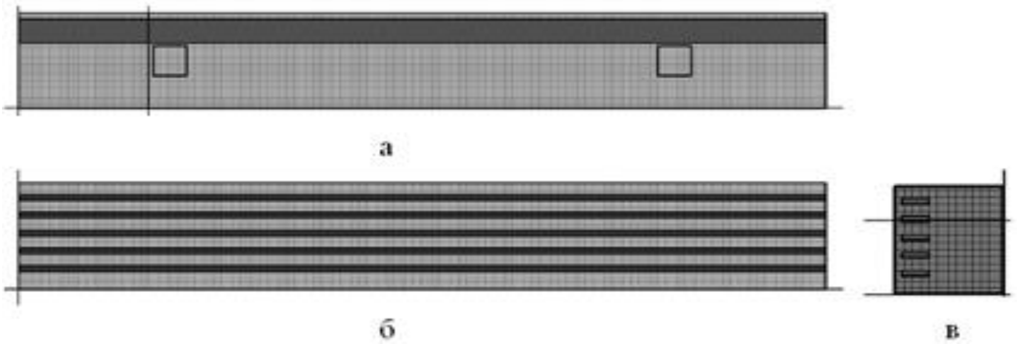

Fig. 6. Grid model of the cable tunnel space: a - y-view of the XY plane; b - XZ view; c - YZ view.

Therefore, you need to strike a balance between the required calculation accuracy and the time required to perform the calculation.

To account for the presence of cable lines, the size of the computational grid is selected so that the cell surface coincides with the surface of the cable line model. In this way, both convective and radiant heat transfer between the combustion area and the solid surfaces of the cables are taken into account most accurately (Fig. 6).

To take into account the heterogeneity of the material from which the cable lines are made, as well as the conditions of conductive heat transfer (heat conduction in a solid material), the cable lines are specified as a multi-component material. Polyvinyl chloride for wire insulation and copper for cable manufacturing are combined. In addition, it is taken into account that the insulation material burns out. This parameter is specified through the bulk density and linear burnout rate. The thermophysical characteristics of the materials and the conditions of convection and radiation heat transfer are shown in Table 1.

Table 1.

Thermal characteristics of materials and conditions of convection and radiation heat transfer

Characteristics	Units of measurement	Value [9].
Thermal and physical characteristics of the insulation material (polyvinyl chloride)		
Thermal conductivity coefficient	W/(m□ K)	0,159
Specific heat capacity	J/(kg□ K)	1320
Density	kg/m^3	1400
Degree of blackness	-	0,85
Thermal characteristics of the wire material (copper)		
Thermal conductivity coefficient	W/(m□ K)	390
Specific heat capacity	J/(kg□ K)	420
Density	kg/m^3	8900
Degree of blackness	-	0,7
General values		
Stefan Boltzmann's steel	W/(m^2□ K)^4	5.67□ 10^{-8}

In order to determine the most significant parameters of the cable tunnel on which the temperature regime of the fire depends and the limits of their variations, a number of computational experiments were carried out to determine to what extent a certain parameter (geometric dimensions, fire load, etc.) affects the temperature regime of the fire in the cable tunnel. To determine the significance of a particular parameter, a mathematical modelling of the fire was first performed at average parameters, and then the parameter was increased and decreased to extreme values. After obtaining 2 new samples and comparing them with the first one, the relative deviation of the temperature-time curves of the fire regime in the cable tunnel was calculated. Each computational experiment, for convenience, is denoted by a Roman numeral and has its own name. Symbols for tunnel elements in computer models: L - distance between holes for combustion products outlet, m; Y - tunnel width, m; Z - tunnel height, m; Q - fire load of one cable line, MJ/m^2 ; N - number of cable lines; n - number of ventilation and inspection hatches; S - area of ventilation and inspection hatches, m^2 .

I. Basic computational experiment on mathematical modelling of a fire with average parameters: L = 10 m; Y = 2 m; Z = 2.15 m; Q = 1380 MJ/m^2 ; N = 5; n = 2; S = 0.3 m^2 .

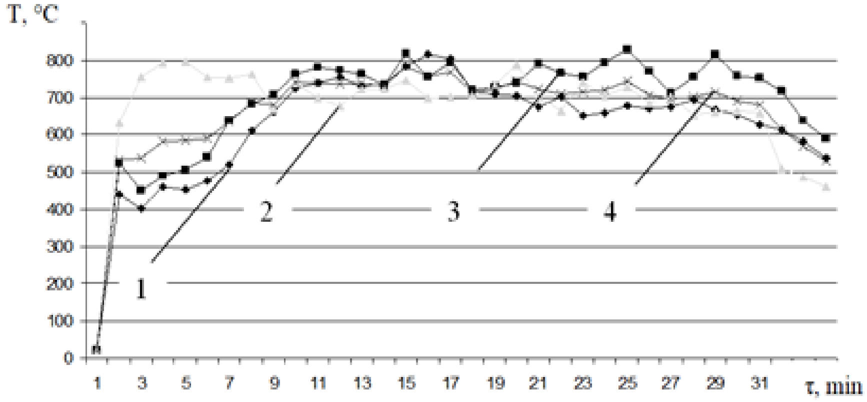

Fig. 9. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 3: 1 - average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3.

II. The impact of fire load.

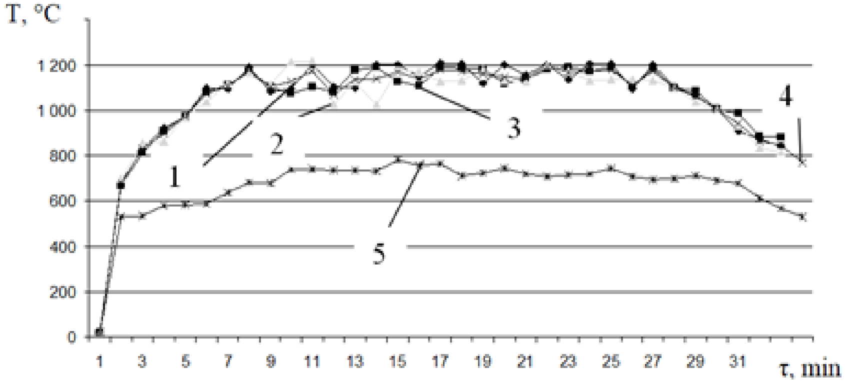

Fig. 10. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 4: 1 – average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3; 5 - average temperature of the baseline experiment (Fig. 9, graph 4).

Parameters of the cable tunnel used in the "maximum fire load" experiment: L = 10 m; Y = 2 m; Z = 2.15 m; Q = 2000 MJ/m^2; N = 10; n = 2; S = 0.3 m^2.

Parameters of the cable tunnel used in the "minimum fire load" experiment: L = 10 m; Y = 2 m; Z = 2.15 m; Q = 688 MJ/m^2; N = 2; n = 2; S = 0.3 m^2.

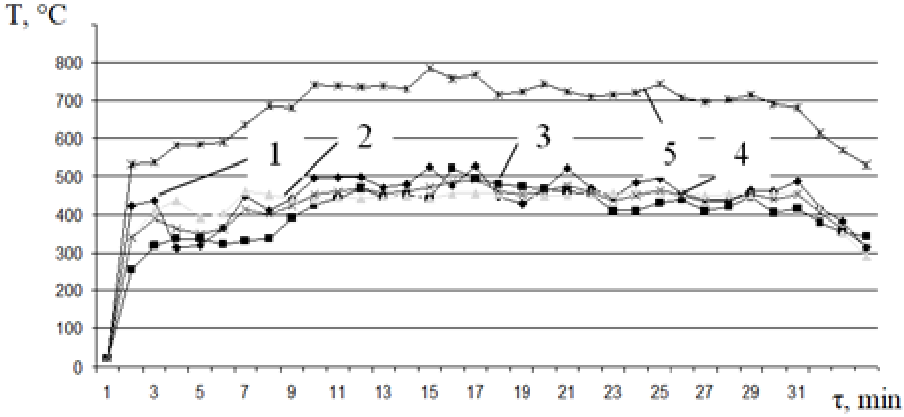

Fig. 11. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 5: 1 - average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3; 5 - average temperature of the baseline experiment (Fig. 9, graph 4).

III. Influence of geometrical dimensions of the cross-section.

The maximum size of the geometric section was included in the basic experiment.

Parameters of the cable tunnel used in the "minimum cross-section" experiment: L = 10 m; Y = 1.6 m; Z = 1.8 m; Q = 1380 MJ/m^2; N = 2; n = 2; S = 0.3 m^2.

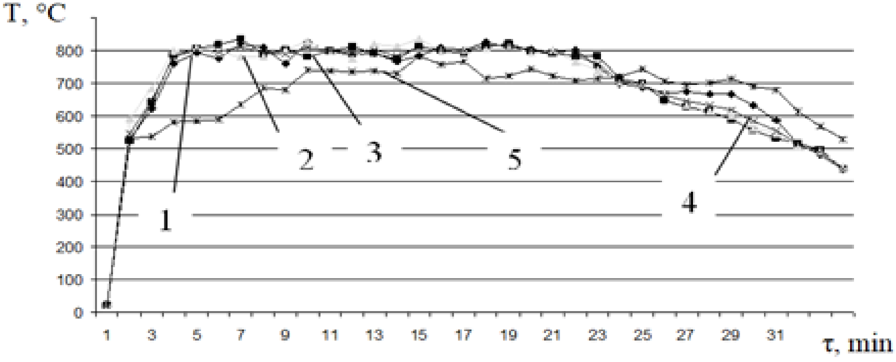

Fig. 12. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 6: 1 - average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3; 5 - average temperature of the baseline experiment (Fig. 9, graph 4).

IV. Influence of geometric parameters of ventilation and inspection hatch openings and the distance between them: L = 10 m; Y = 2 m; Z = 2.15 m; Q = 1380 MJ/m^2 ; N = 2; n = 1; S = 0.3 m^2.

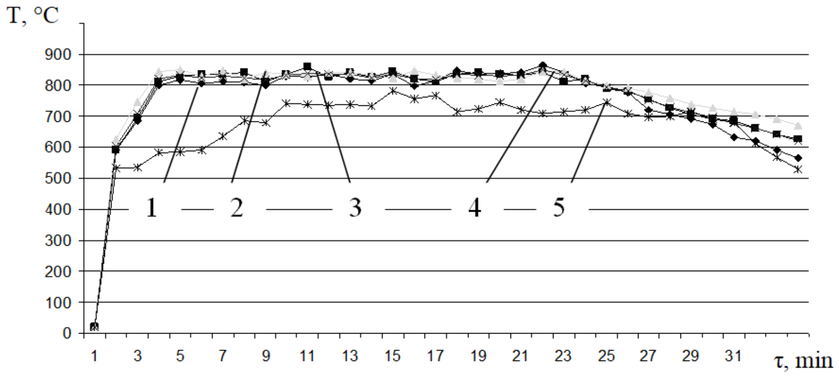

Fig. 13. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 7: 1 - average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3; 5 - average temperature of the baseline experiment (Fig. 9, graph 4).

Parameters of the cable tunnel used in the experiment "maximum air inflow": L = 5 m; Y = 2 m; Z = 2.15 m; Q = 1380 MJ/m^2 ; N = 2; n = 3; S = 0.3 m^2 .

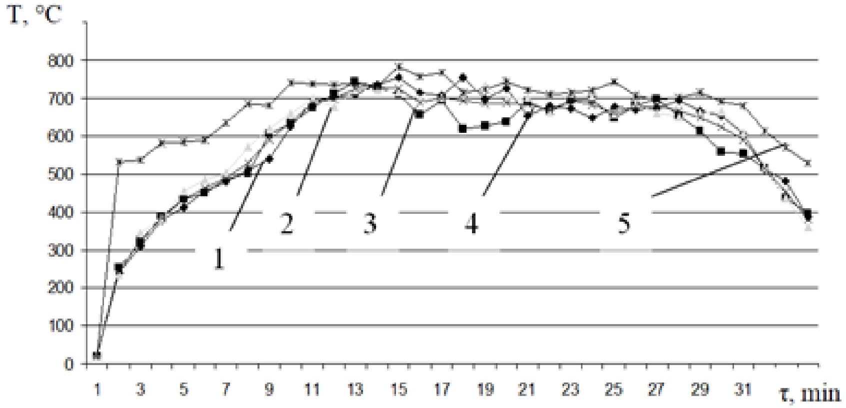

Fig. 14. Temperature regimes of the fire in the mathematical model of the cable tunnel with the parameters specified in Table 8: 1 - average temperature in the plane of the fire centre; 2 - average temperature in the plane "-0.5 m" from the fire centre; 3 - average temperature in the plane "+0.5 m" from the fire centre; 4 - average temperature between graphs 1-3; 5 - average temperature of the baseline experiment (Fig. 9, graph 4).

V. Averaged results

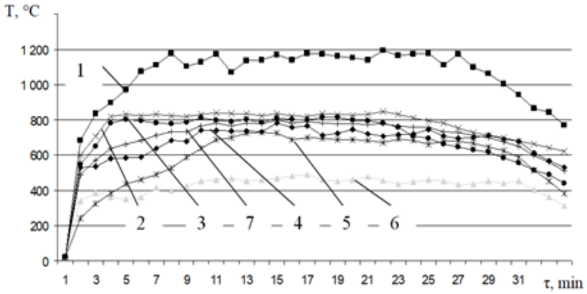

Fig. 15. Averaged fire temperature regimes in the mathematical model of a cable tunnel with the parameters given in Tables. 4 - 9: 1 - average temperature of the computational experiment "maximum fire load"; 2 - average temperature of the computational experiment "minimum air inflow"; 3 - average temperature of the computational experiment "minimum cross-section"; 4 - average temperature of the computational experiment "baseline experiment"; 5 - average temperature of the computational experiment "maximum air inflow"; 6 - average temperature of the computational experiment "minimum fire load"; 7 - average temperature between the graphs 1-6.

Analysing the results obtained, it can be stated that the fire temperature regime is most influenced by the fire load, air inflow rate (horizontal component of the velocity), and geometric parameters of the tunnel.

Conclusions and prospects for further research. The paper determines the temperature regimes of fires in cable tunnels with different sizes, aerodynamic parameters and fire load, as well as the dependence of the fire temperature regime on these parameters. With 10 laid cable lines and a fire load of