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Approach to Assessment of Time of Evacuation of People in the Conditions of Influence of Dangerous Factors of the Fire in System of Imitating Modelling of Fire-Dangerous Situations

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Abstract: Research object in work is software of systems of imitating modeling of origin and development of fire-dangerous situations, systems of fire safety and systems of decision support in case of evacuation of people from zones of impact of dangerous factors of the fire. In work approach to a time estimate of evacuation of people in the conditions of impact of dangerous factors of the fire in system of imitating modeling of fire-dangerous situations for various options of the rooms differing in options of development of a fire-dangerous situation is offered. The offered approach can be used in system of forecasting and a risks assessment of fire-dangerous situations which can be used in the analysis of systems.

Key words: Imitating modeling, fire risk, fire-dangerous situation, dangerous factors of the fire, imitating model, forecast, risk assessment

INTRODUCTION

Now imitating modeling of the fires becomes defining at the solution of various problems of fire safety in various branches. The special place is allocated at the same time to problems of safety of people at evacuation and fire extinguishing in the organizations which are characterized by usually big congestion of people (Helbing *et al*., 2000).

It should be noted that in the majority of techniques on fire safety the simplified methods of calculation (Hassanain, 2006) which aren't reflecting the difficult, dynamically changing, nondeterministic, stochastic picture of the real fire which is characterized by essential three-dimensionality and unsteady are put.

At the same time works in this direction are actively conducted (Yemelyanov *et al*., 2014). As one of perspective techniques is considered imitating modeling of processes of distribution of the fires (Frolov and Yu, 2013; Zotov *et al*., 2012). Already existing and continuously improved imitating and mathematical models of the fire indoors allows to simulate and lose various options of distribution of the real fire.

The fire-dangerous situations investigated in work have complex internal structure, are characterized by hierarchy of management and activity of separate subsystems, interaction of elements taking into account the nature of impacts of the external environment on internal structure.

MATERIALS AND METHODS

The existing approaches to assessment of time of evacuation of people: The main method to ensure the safety of people in case of the fires in buildings is their timely evacuation to places, safe concerning the fire, in the building or out of the building. Time of movement of people from those places to the placement or the building where they can be affected by dangerous factors of the fire, to the safe place is called estimated or actual time of evacuation. Time during which dangerous factors of the fire reach values, maximum permissible for the person, is called critical time of the fire. The critical time taken with a certain coefficient of an inventory (usually 0,8), is called necessary time of evacuation. As criterion for evaluation of safety of people in case of the fires the risk determined as probability of impact of dangerous factors of the fire per capita can serve. The existing regulating documents established the following criteria of safety of people in case of the fires:

The probability of impact of dangerous factors of the fire on people in case of his emergence and uncontrollable development is determined by a Equation:

$$Q_p = (1-\text{Đ}_e)\cdot(1-\text{Đ}_{pz}) \tag{1}$$

Where:

P_e = Probability of successful evacuation of people to the safe place

P_{pz} = Probability of effective operation of engineering fire protection systems

The admissible size of probability of impact of dangerous factors of the fire on the person according to GOST 12.1.004-91 "Fire safety. General requirements" should not exceed 10-6 per person / year. The probability of successful evacuation of people is determined by comparison of necessary time of evacuation with settlement.

Estimated and necessary time of evacuation: For ensuring safe evacuation of people from the room or the building in case of the fire the condition shall be complied:

$$\tau_p \leq \tau_{Hb} \quad (2)$$

where:

- τp = Estimated (actual) time of evacuation of people from the room or the building,
- τ_{Hb} = Necessary time of evacuation, s

Density of a human flow: In case of accumulation of big mass of people which can arise in case of the fire or other emergency their successful evacuation requires observance of a condition

$$D \leq Dmax \quad (3)$$

where:

- D = Density of a human flow, person/m^2 or m^2/m^2;
- D_{max} = The maximum density of a human flow, person/m^2 or m^2/m^2

Processes of distribution of products of burning on the building and movements of human flows are determined by a number of factors which have accidental nature. The approaches based on consideration of processes of origin and development of a fire-dangerous situation on the basis of fuzzy logic (Zotov *et al*., 2012) of neural networks (Sazonov *et al*., 2015) and multi-agent approach (Yemelyanov *et al*., 2014; Zotov *et al*., 2012) were offered by scientists of Southwest state university.

A quantitative index a successful outcome of the evacuation in a particular situation is taken probability P_e that the evacuation all mass of people is completed in time τp, is not >τHb

$$|P_e = p\{\tau_p \leq \tau_{Hb}\} \quad (4)$$

Estimated time of evacuation is determined as the sum of periods from the moment of emergence of the fire before operation of the warning system and management of evacuation τ_{coy} and time of the movement of human streams by ways of evacuation τ_{db}

$$\tau_p = \tau_{coy} + \tau_{db} \quad (5)$$

The general expression for calculation of probability is received $p\{\tau_p \leq \tau_{Hb}\}$; 0∞:

$$p\{\tau_p \leq \tau_{Hb}\} = \int [\ \int f(\tau p) \cdot \varphi(\tau p - \Delta\tau) d\tau p] d\Delta\tau \quad (6)$$

where:

- $\Delta\tau$ = $\tau p - \tau_{Hb}$; $f(\tau p)$,
- $\varphi(\tau Hb)$ = Distribution densities τp and τHb respectively

For a case when sizes τp and τHb submit to the normal distribution law, dependence is received:

$$p\{\tau_p \leq \tau_{Hb}\} = F[(m\tau_{Hb} - m\tau_p)/(\sigma\tau_p 2 + \sigma\tau_{Hb} 2)0,5] \quad (7)$$

where:

- (Fx) = The normal distribution function;
- $m\tau_{Hb}$, $m\tau_p$ = Mathematical expectations and values τ_{Hb} and τ_p, respectively;
- $\sigma\tau p^2$, $\sigma\tau Hb^2$ = Dispersions of sizes τp and τHb respectively

The probability of operation of fire protection systems P_{pz} can be determined by known methods using indicators of reliability of its individual elements.

RESULTS AND DISCUSSION

A technique of determination of critical and necessary time of evacuation of people from rooms: Critical time of evacuation from the room is determined by such dangerous factors of the fire as temperature, reduction of visibility in smoke, reduction of concentration of oxygen, increase in concentration of toxic components of products of burning.

On achievement of value of temperature of products of burning, critical for the person, necessary time of evacuation is determined by a Equation On decrease in concentration of oxygen in air:

$$T_{kp},T = \{B/A \cdot \ln [1+70 \cdot t_0/(270+tH) \cdot \beta]\}^{1/n} \quad (8)$$

Where:

- B = $(353 \cdot cp \cdot V)/[(1-\varphi) \cdot \eta \cdot Q]$;
- A = $1,05 \cdot \varphi \cdot V2\pi$;
- β = $y/Hexp(1,4 \cdot y/H)$;
- t_0 = The initial temperature of the room,
- °C = On visibility loss

$$T_{kp,pv} = \{B/A \cdot \ln [1+V \cdot \ln(1,05 \cdot \alpha \cdot E)/(l_{pv} \cdot B \cdot D_m \cdot \beta)^{-1}]\}^{1/n} \quad (9)$$

$$T_{kp,O2} = \{B/A\cdot \ln [1\text{-}0,44 /(B\cdot L_{O2}/V+0,27)\cdot\beta]\}^{1/n} \quad (10)$$

On each of gaseous toxic components of products of burning:

$$T_{kp,pg} = \{B/A\cdot \ln [1 - V\cdot x/(B\cdot L\cdot\beta]^{-1}\}1/n \quad (11)$$

where:

- n = The exponent considering change of mass of the burning-out substance;
- A = The dimensional parameter considering the specific mass speed of burning out, kgS^{-1};
- β = The dimensionless parameter considering unevenness of distribution of dangerous factors of the fire on room height;
- Q = The lowest heat of combustion of material, kJ/kg;
- C_p = A specific isobaric thermal capacity of air, $kJkG^{-1}$;
- φ = Coefficient of heatlosses;
- η = Coefficient of completeness of combustion;
- V = Free volume of the room, m^3;
- α = Coefficient of reflection of objects on the ways of evacuation, m;
- D_m = Smoke-generating ability of combustible material, $Np.m^2/kg$;
- L = A specific exit of toxic gases in case of combustion of one kg of material, $kgkg^{-1}$;
- x = Maximum permissible content of toxic gases indoors, kg/m^3;
- L_{O2} = a specific consumption of oxygen, kg/kg.

The technique of definition of critical time of evacuation offered above from rooms is based on the integrated model of development of the fire considering the room as uniform volume. For rooms of the big sizes the approach based on use of jet or zonal models is represented more adequate. When using such models as critical time of evacuation it is possible to accept time of lowering of a layer of smoke indoors to the set level from half of the room

$$\tau_{kp} = 6,39\cdot S_{pom}\cdot(z^{-0,5} - H^{-0,5})/P_f \quad (12)$$

where:

- τ_{kp} = Critical time of evacuation, with;
- S_{pom} = Area of half of the room, m^2;
- z = Height of the lower bound of a layer of smoke over half of the room, m;
- H = Room height;
- P_f = perimeter of the seat of fire, m.

We will assume that in the small room in the building there were people, but the main emergency exit was already blocked. And though in the room there is no fire, but burning products (gas, smoke) in the neighboring room get into this room. In such situation possible time for extraordinary evacuation, for example through windows, is determined by concentration of harmful gases and smoke indoors. Until it reached maximum permissible value, the people who are cut off from an exit can be evacuated by live.

Therefore it is necessary to remove a formula of growth of concentration of harmful gases in this room. We will designate through Δ_g amount of the gas arriving from the neighboring room in unit of time. It is natural that the same amount of air flows away from this placement to the external environment. α_g concentration of harmful components in the filtered gas (in Δ_g). Δ_g it is possible to consider a constant as the fire situation in the neighboring room is in the developed phase. Before there was a probability of evacuation through the main exit that in our assumptions is already missed. α(t) concentration of harmful gases indoors in time point t. Then the ratio takes place:

$$\alpha(t+1) = \frac{(v-\Delta_g)\alpha(t)+\Delta_g.\alpha_g}{v} \quad (13)$$

Where:

V = volume of the room.

If we consider this ratio is not a unit of time, and for the time increment , we get:

$$\alpha(t+\Delta_t) = \frac{(v-\Delta_g\Delta_t)\alpha(t)+\Delta_g.\alpha_g.\Delta_t}{v} \quad (14)$$

Transform:

$$\begin{aligned} &v.\alpha(t+\Delta_t) = v.\alpha(t)+\Delta_g\alpha_g.\Delta_t;\\ &v(\alpha(t+\Delta_t)-\alpha(t) = \Delta_g\alpha_g.\Delta_t);\\ &v\Delta\alpha = \Delta_g(\alpha_g-\alpha)\Delta_t;\\ &v\frac{\Delta_a}{\Delta_t} = \Delta_r(\alpha_g-\alpha)\text{or } v\alpha = (\alpha_g-\alpha)\Delta_g \end{aligned} \quad (15)$$

This ordinary differential equation with the separated variables:

$$\frac{d\alpha}{\alpha_g-\alpha} = \frac{\Delta_g}{v}dt \quad (16)$$

We integrate on [0, t]

$$-\text{In}|\alpha_g-\alpha| + \text{In}|\alpha_g-\alpha(0)| = \frac{\Delta_g}{v}t \quad (17)$$

$$\text{In}\frac{\alpha_g-\alpha(t)}{\alpha_g-\alpha(0)}=-\frac{\Delta_g}{v}t \quad (18)$$

Potentiation of this ratio, we will receive:

$$\text{In}\frac{\alpha_g-\alpha(t)}{\alpha_g-\alpha(0)}=-\frac{\Delta_g}{v}t,\text{i.e}\alpha(t)=\alpha_g-\alpha(0)e-\frac{\Delta_g}{v}t \quad (19)$$

where $\alpha(0)$ – an initial condition of concentration of harmful gases (in usual air).

If α_{kp} - critical concentration of harmful gases, then t_{kp} short value $\alpha(t_{kp})$. And for ?will be carried out inequality: $\alpha(t)>\alpha_{kp}$ and:

$$t_{kp}=\frac{\Delta_g}{v}\text{In}\frac{\alpha_g-\alpha_0}{\alpha_g-\alpha_{kp}} \quad (20)$$

We will designate through M – amount of combustible material of the different types which are in this room. For example, furniture, paper, books, etc.

We will designate through Q^p_H -average amount of the generated heat at combustion of one unit of total mass of combustible material.

If through V to designate internal energy of gas indoor environment, and t – time, then the equation of energy looks as follows:

$$\frac{dv}{dt}=rQ_H^{P\psi}+i_r\psi+c_mT_BG_B-c_pT_mmG_r-Qm \quad (21)$$

where:

- ψ = The average speed of burning out (gasification speed) of combustible material (km/s); r – coefficient of completeness of combustion;
- i_r = An enthalpy of combustible materials; i.e. indicator of their gasification;
- G_B = Consumption of the arriving air from the environment, and the composed $C_m\ T_B\ G_B$ – value of internal heat energy of the air arriving for a unit of time and the corresponding work of pushing through;
- G_r = A consumption of the gas leaving the room, and the relevant composed $C_m\ T_m\ mG_r$ – value of internal heat energy of the leaving gas in the amount with work on its pushing out from the room;
- Q_m = The thermal flow absorbed by the protecting designs and radiated through apertures

For assessment of a temperature maximum it is (estimated) possible to neglect the third, fourth and fifth composed. Then we have integrated assessment of internal heat energy:

$$v_{max}\approx\left(rQ_H^{P\psi}+i_r^{\psi}\right)M+v_o \quad (22)$$

As the volume of the room does not change,at the corresponding coefficient of k. we get:

$$T_{max}=V_{max}.K \quad (23)$$

So we receive the upper bound of temperature condition, i.e. we can estimate risk of impact of the fire on a design taking into account coefficients of temperature stability of the corresponding materials.
From the relation p/T = c.V,
where:

- V = volume, T- Temperature and
- p = the pressure of the gas

Therefore, through the T_{kp} and the critical pressure is determined.

$$p_{max}=c.V.T_{max} \quad (24)$$

It gives an assessment of risk of destruction of windows, doors, etc. designs. For each such design there is a tabular value of pressure difference which this design can sustain. It gives the chance to estimate probability of transition of fire from the considered room at others, due to destruction of partitions, interior doors, etc. In case of destruction of a barrier between the room where there is a process of burning and the adjacent room, for the adjacent room initial is a source on pressure, temperature, harmful gases, smoke, etc.

Then it is necessary to calculate the course of process of burning on system of the differential equations:

$$\begin{aligned}
&p_m=\rho_mRT_m;\frac{d(\rho_mv)}{dt}=G_\beta+\psi-G_r\\
&\frac{d(\rho_1v)}{dt}=x_{1\beta}G_\beta-x_1n_1G_r-\psi L_1\eta\\
&\frac{d(\rho_2v)}{dt}=\psi L_2\eta-x_2n_2G_r\\
&\frac{d(\mu_mv)}{dt}=D\psi-\frac{\mu_mn_3}{\rho_m}G_r-K_cF_w\\
&\frac{1}{K-1}\frac{d(\mu_mv)}{dt}=\eta Q_H^{\rho\psi}+i_r\psi+c_mT_BG_B-c_pT_mmG_r-Q_w
\end{aligned} \quad (25)$$

With the initial conditions approximate calculations with constant rather small step on time.

$$\begin{aligned}&\rho_m(t=0)=\rho_0;p_m(t=0)=\rho_0;\rho_1(t=0)=\rho_{01};\\&\rho_1(t=0)=0;\mu_m(t=0)=0\end{aligned} \quad (26)$$

At excess of indicators of temperature, pressure of their critical conditions to consider changes of communication with the environment. For example, when glasses break, in process of burning there is free an air access. And at destruction of a doorway the aperture of leak of smoke, gases and even fire to the neighboring room opens.

CONCLUSION

The results received in work can be used in system of forecasting and a risks assessment of fire-dangerous situations which is applied in the analysis of systems of fire-proof providing, preparation and retraining of specialists of fire-proof protection taking into account requirements of modern standards of safety. The mathematical ratios received in work can be used in case of development information and the software of fire protection systems and systems of imitating modeling of distribution of the fires

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