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The solution of fire safety problems under a design stadia with computer fire and evacuation simulation

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Abstract. It is shown in the paper how fire evacuation simulation can be applied to check fire safety and find safe conditions under design stadia of the building. Mathematical background of fire and evacuation simulation is presented. An ice stadium is considered as an example.

1. Introduction

The design of buildings and structures is accompanied by an answer to a question: does the design solution meet the requirements of fire safety? According to the Russian Fire safety code (123-FZ of 22.07.2008) a simulation of fire and evacuation is used to confirm the compliance of the venue with fire safety requirements both in terms of compliance with mandatory requirements and in the case of deviation from the requirements of voluntary application within the calculation of fire risk [1].

The stages of a simulation are: (*) a formulation of the scenarios; (*) a construction of a 3D-model of the building (or its import from BIM-model), (*) an allocation of the computational area, (*) a setting the initial and boundary conditions, (*) simulations, (*) a visualization and analysis.

Both components should be done: the simulation of fire spread, and the simulation of the evacuation, as well as a consequent a space-time analysis of simulation results, consisting in the correlation of the blocking and evacuation times at control points.

Modern simulation software meets a requirement which is to combine the ability to perform both simulations on the basis on one building model. The unified format of the initial data allows automating the task of control points and a joint analysis of both simulations. This tendency makes simulations effective, eliminates accidental errors and the human factor.

Import of a BIM-model is a significant acceleration of simulation procedures, so the analysis of design decisions can be performed repeatedly.

Modern computer graphics technologies allow performing a visualization of simulation results [2], which greatly facilitates the analysis of the performed calculation and design solution.

2. Mathematical models

To simulate evacuation a model of individual-flow type is developed and coded in “Sigma SF” software [3-5]. CFD modeling is used for fire spread simulations [6-8].

2.1. Evacuation model

People are considered individually as individual particles (incompressible flat discs ranging in area from 0.05 to 0.9 square meters, which move in a plane within the scope of the simulation, a set of available directions is limited.

An unimpeded speed of a particle can be set individually and ranges from 0.5 to 2 m/s. At each computational step, a new position of each individual is calculated, and other people, obstacles and destination point are taking into account. By controlling the parameters of the model, it is possible to reproduce the movement from a strictly directed (when a person moves the shortest path to the goal, for example, the exit from the building), to random – irrational (characteristic of a panic behavior). It is known that with an increase of a density, a speed of a person decreases, and with density of about 10 people per square meter, speed decreases to almost zero. This dependence has an analytical expression [1, 6]. And this fact is also taken into account by the model of pedestrian flow.

As a result, the movement of each individual and the phenomena peculiar to the flow of people are simulated: merger, reshaping (spreading, compaction), non-simultaneous merging of flows, formation and deformation of congestions, flow around turns, movement in rooms with a developed internal layout, counter-flows and intersecting flows [3-5].

2.2. Fire spread

Modern computers allow an everyday using of such powerful simulation tool as CFD modelling for fire spread simulations [6 - 8]. It provides an approximate three-dimensional solution to the equations governing fluid motion. Modelling area is divided into very large number of small computational domains, referred to as mesh, or, grid cells. Complex geometries and time-dependent flows are readily handled. The solution is values of flow parameters of interest, such as velocity and gas concentration, calculated at each cell. It provides a complete three-dimensional, time-dependent picture of complex fluid flows.

CFD modeling technique is wide spread and well investigated already. Here we only mention algorithms that are used in our CFD code and implemented in Sigma FS© fire evacuation software [2, 9-11]:

- a numerical method: finite-volume methods;
- a calculation of cell-center gradient: least-squares method;
- convective terms: UDS, QUICK, UMIST TVD, Superbee TVD;
- a pressure-velocity coupling: SIMPLE-like algorithm with Rhie-Chow interpolation (collocated grid arrangement);
- a solution of algebraic equation systems: conjugate-gradient method, conjugate-residuals method, multigrid techniques (AMG);
- an approximation of unsteady terms: implicit 2nd order method;
- parallelization: domain decomposition, MPI.

To model turbulence, Shear-Stress Transport k-ω model (Reynolds-Averaged Approach - RANS) is used. To resolute near-wall regions blending the viscous sublayer formulation and logarithmic layer formulation are implemented. For highly unsteady flow is unsteady RANS-model.

The iterative procedure used to obtain a solution requires a measure to determine when a satisfactory solution has been reached. There are two criterions: number of iterations and value of residuals.

Note that Shear-stress transport model for turbulence has an advantage comparing with Large Eddy Simulation (LES) which is used in the well known CFD code FDS. LES model requires sufficiently fine grid resolution to resolve the important flow structures - 1-5 cm versus 10-20 cm for Shear-Stress Transport model.

To model fire the following combustion model for solid fuels is used:

$$\Psi = \psi_s \cdot \pi v^2 t^2 ,$$

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where Ψ is a rate burnout, kg/s; ψ_s is a specific rate burnout, kg/(s·m^2); v is speed of fire spread, m/s; t is time in seconds. The speed of volatile is $\varphi_{\text{volatile}} = \alpha \cdot \Psi$, kg/s.

3. Case study

The use of computer simulation allows studying the development of an emergency situation in accordance with different scenarios. Under scenario of fire we assume combination of space-planning solution and engineering systems (anti-smoke ventilation, alarm and evacuation control systems). Here we present influence of space-planning solution on evacuation rout conditions for 2600 seats ice stadium.

In a case of fire it is necessary to ensure the safe evacuation of people from a building. Russian regulations require that two conditions should be met during evacuation: unhindered and timely [1]. Unhindered means that evacuation routes are not congested with a density of more than 3.5 persons per square meter lasting more than 6 minutes. Timely evacuation means a way to a safe place is not effected by hazardous factors (e.g., smoke) which reach unsafe concentrations.

3.1. Stadium design

The stadium is designed for 2600 seats and consists of two blocks. The administrative part and several training halls are located in Block A. The bowl of the stadium is in Block B, which has 2 stands (East and West). Each stand has 4 sections. Blocks A and B are connected through the transition. The entrance to the building is located on the South side. Through the open stairs the lobby of the ground floor is connected with the first floor. Loading/unloading of the bowl by the spectators is carried out through the hatches located on the first floor, Figure 1. Each sector is provided with its own hatch. There are places provided for people with limited mobility. They are accessed through the ground floor, hatches H M4.1, H M4.2.

From the second floor there are 2 closed stairs leading directly to the outside from the West and East sides. From the North-West side there is an exit to the open staircase. The transition to Block A is in the North side and have got fire door. On the South side there are 2 open stairs connecting the central lobby of the ground floor with the second one.

The perimeter of the first floor has a through passage and is divided by conventional doors into 4 sections (doors 1-4 in Figure 1). At the same time, there is the following feature of the Western and Eastern sides, Figure 1: one section includes a food-court and 3 hatches (Hatches 6-8 and 1-3 respectively), Hatches 4 and 5 have an exit in one section, fenced off from the sections with food-courts with Doors 2 and 3. This feature of the space-planning solution is the subject of consideration in this article.

3.2. Fire scenario

There was considered a seat of fire in the food-court on the West side, see Figure 2. Evacuation starts 60 seconds later. Spectators of the East tribune leave their sector through their Hatches 1-4, M 4.1. And then they take the nearest stairs to go directly outside of the building. The most close to the fire are the hatches 6-7 of the Western tribune, so they are immediately excluded as possible ways. Hatches 5, 8, M 4.2 are potentially possible hatches for evacuation of the spectators of the Western tribune. Spectators of the East stand leave their sector through their hatches 1-4, M 4.1. And then they use the nearest stairs directly outside of the building.

3.3. Developing of fire

Simulations were done with Sigma FS simulation tool. Figure 2 presents evacuation and optical fire density 70 seconds later than fire starts. One can see horizontal plane of optical density of a smoke at the height 1.7 m. Conditions near Hatch 8 are safe at this time, people don’t see the seat of fire and move freely.

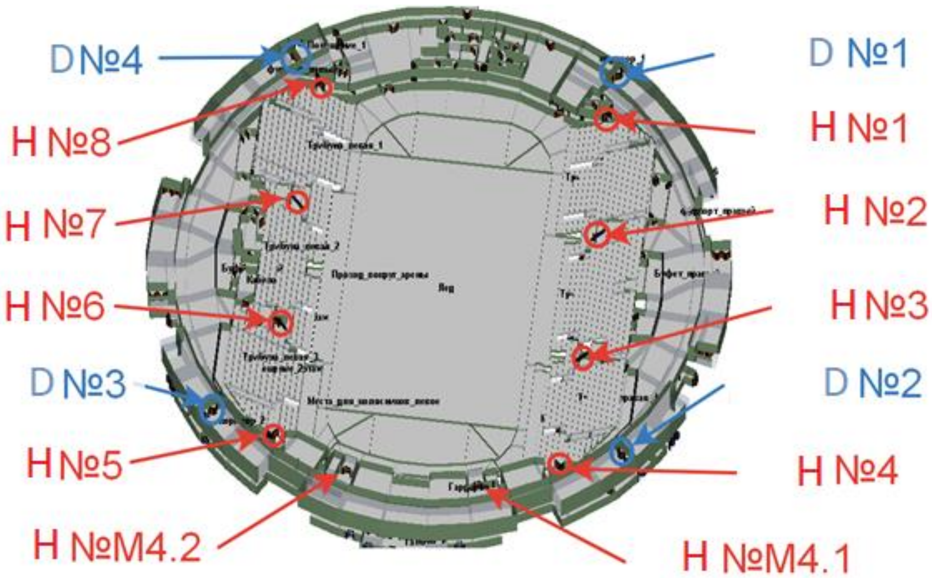

Figure 1. Position of hatches (H) and doors (D) on the 1-nd floor.

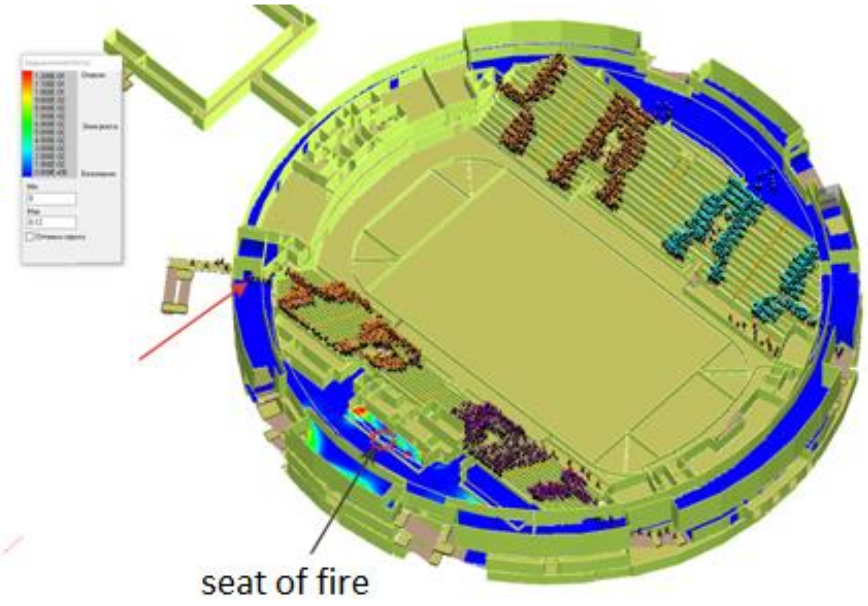

Figure 2. Evacuation from tribunes and 1.7m - optical density of a smoke (blue –color is for safe place, red color is for dangerous regions), *t*=70 s.

But after 160 seconds situation is changing. Smoke freely moves to the Door 4 and reaches critical value, Figure 3. Under such conditions evacuation is impossible. Thus only Hatches 5 and M 4.1 could be used.

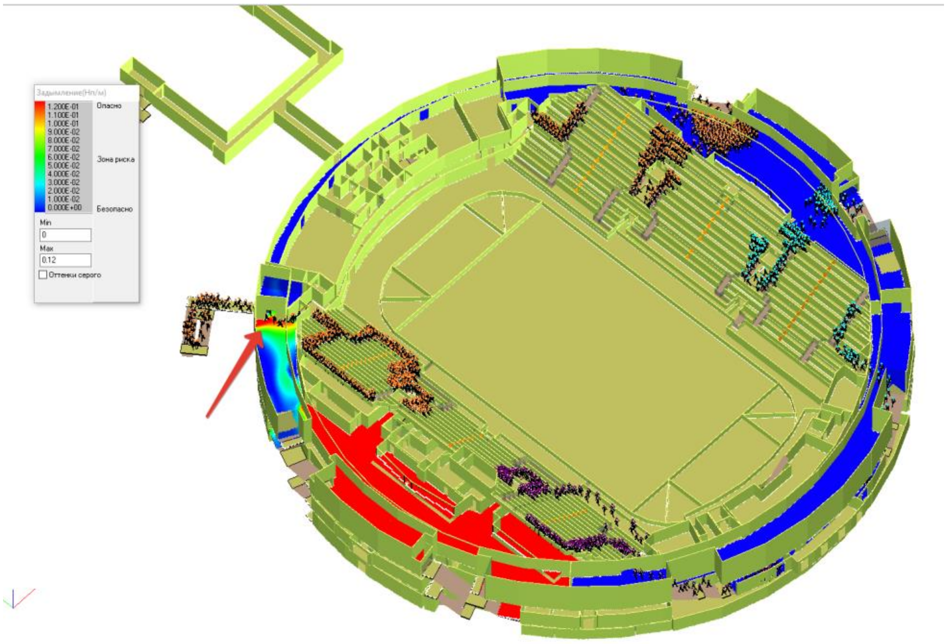

Figure 3. Evacuation from tribunes and optical density of a smoke (blue –color is for safe place, red color is for dangerous regions), *t*=160 s.

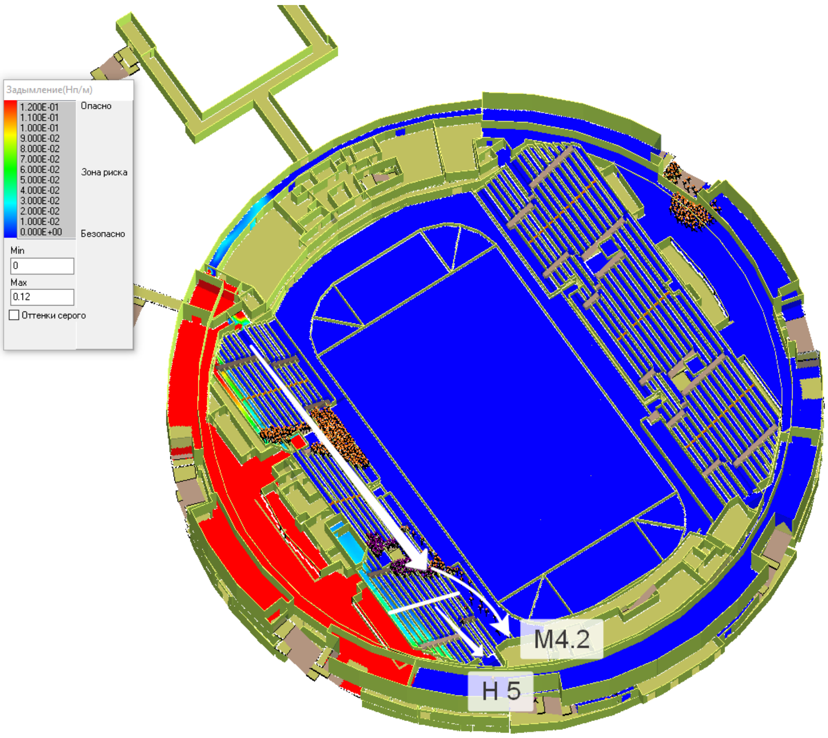

Figure 4. Evacuation from tribunes and optical density of a smoke (blue –color is for safe place, red color is for dangerous regions), *t*=290 s

Total capacity of Hatches 5 and M 4.1 considerably lower. The Hatch 5 could be used only by spectators of the 5-th sector due to restrictions in the rows. Spectators (about 1000 people) from the 6-8-th sectors can leave tribunes only using H M4.2. The Door 3 does not allow smoke spread to the evacuation way from Hatch 5 (the smoke does not reach lobby in the first and ground floor). But in this case evacuation takes more than 600 seconds, there are long last dense (not safe) congestions on the tribunes, see Figure 4.

4. Conclusion

The example considered shows that space-planning solution of the first floor and tribunes as they were designed does not provide safe conditions during fire evacuation. It becomes evident using computational simulation of fire spared and evacuation. The appropriate decision of the situation could be tested with the simulation.

Design stadia is the best (and the cheapest) moment to provide building with fire safe solution. Import of BIM-model is a significant acceleration of simulation procedures, so the analysis of design decisions can be performed repeatedly.

Acknowledgments

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