Experimental research of human evacuation in the case of a fire drill

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Abstract. The main purpose of this study is to analyze the human evacuation in the case of a fire drill by two different means: experimental research - “real fire drill” and numerical simulation - “virtual fire drill”.

The analyzed building can house a large number of people and its inner atrium can facilitate the spread of smoke and hot gases in the case of a real fire.

The evacuation drill was performed with about 50 students, located at the 2nd floor of the building, in two amphitheaters. They could evacuate themselves through two closed staircases to the ground floor of the building and then outside, through two exit doors.

The second purpose of this study is to establish, for the given case, if the used computer software can simulate the crowd movement and compute the travel times in accordance with the experimental research.

Another important subject is whether the computer software FDS+Evac - based on the CFD (Computational Fluid Dynamics) to simulate the crowd movement - can correctly identify the shortest escape path because one of the staircases, with its correspondent ground floor exit, is closer to the two analyzed amphitheaters.

Following the numerical analysis, it was concluded that for the considered scenario, the differences between the “real fire drill” and the “virtual fire drill” are acceptable from an engineering point of view.

FDS+Evac can simulate with high degree of credibility human movement in case of a fire drill.

KEYWORDS: fire drill, FDS+Evac, numerical simulation, CFD (Computational Fluid Dynamics), educational building, finite volume method.

1. Introduction

The purpose of this study is to analyze the human evacuation in case of a fire drill by two different means: experimental research and numerical simulation.

The experimental program presented in this paper (studied in detail by the author in his PhD Thesis [1]) addresses a direction of fire safety engineering less studied by researchers, considering the limited number of publications on human movement in case of real fires or in fire drill, as this process takes place in reality.

The numerical simulation – “virtual” fire drill – of the human movement in the analyzed building was performed and the results have been compared with those obtained from the “real” fire drill (evacuation time and escape route choosing).

2. Description of the experimental program

The considered building (Figure 1) is part of the Faculty of Construction and Building Services of the “Gh. Asachi” Technical University from Iasi, Romania.
The experimental program involves a fire evacuation drill from the building and monitoring the evacuation process with the help of the video surveillance system. The occupants of the building are students and staff of the faculty (teaching staff and auxiliary staff). The users of the building are mainly young people (for students, the age range is between 20 and 25 years old), without psychic or motor disabilities and with a high-level of knowledge about the building. The fire drill was planned, the users of the building being informed by posters of the date and time, but also, in particular, how to behave in case of such an event of evacuation. The evacuation paths of the analyzed spaces are shown in Figure 2 for the first floor of the building and in Figure 3 for the ground floor of the building.

3. The results of the experimental program
A total of 53 people participated in the evacuation drill, including 3 teachers and 50 students. The attending people were studying in two amphitheaters and a classroom, rooms located on the first floor of the building.
Figures 4÷9 show the movement of people, at different times, from the escape routes to the exterior of the building.

As a result of the evacuation drill, the following conclusions could be drawn:

• at the start of the alarm system, the participants responded firmly, gathering their personal belongings and leaving the rooms where they were studying;
people travelled through the escape routes to the outside of the building in an orderly manner;
- only the main staircase and the main exit of the building have been used;
- the reaction time, measured from the moment when the alarm system was triggered till the first persons left the room, was 15 s;
- the movement time, measured from the moment when the first persons left the room till the last persons left the building, was 75 s;
- average movement speed, $v = 1.1\div1.7$ m/s (uniform distribution);

**FDS+Evac – short description**

Fire Dynamics Simulation with Evacuation (FDS+Evac 2.5.0) is a human evacuation module implemented in the Fire Dynamics Simulator (FDS) software. The program is based on the analogy of crowd movement – fluid flow, considering the fire – people interaction. FDS+Evac deals with each evacuee (called by the software “agent”) as a single entity whose movement is controlled by a time-dependent equation. Each individual has his own properties and strategies for evacuation. The agents are subjected to moment and contact forces, deriving from psychological behaviour and displacement [2], [3].

People are modelled as agents moving in 2D geometries within the boundaries of the building floors (Figure 10 a). The plane size of each agent is estimated using 3 circles approximating the elliptical shape of the human body (Figure 10 b). FDS+Evac uses stochastic properties for agent characteristics. The motion equation, due to the granted degrees of freedom for translation and rotation, was solved by using specific methods for dynamics of dissipative particles. The model uses continuous time and space to trace agent trajectories (Figure 10 c).

![Figure 10. FDS+Evac agents movement modelling [3]](image)

**4. Numerical simulation**

In the FDS+Evac the whole building was analyzed. The virtual model with finite volumes is presented in Figure 11. The location of the agents in the virtual computational domain is illustrated in Figure 12. Their location at time 0 (in the “virtual evacuation drill”) corresponded to the moment when the “real evacuation drill” was started.

For generating the FDS and FDS+Evac input data, PyroSim (graphic user interface) was used. In the numerical model, people were placed just like in the case of the “real” fire drill – 53 agents located in 3 classrooms on the first flood of the building. For the accuracy of the obtained results, the furniture in the classrooms has been modelled as obstacles for the moving agents.

The following characteristics, Figure 13, have been considered in the behaviour and agent modelling:
- detection time: 0 s (evacuation drill);
- reaction time: 15 s (taken from the “real” evacuation drill”);
- displacement speed: $1.1\div1.7$ m/s (taken from the “real” evacuation drill”);
- software’s default dimensions of the human body (correspond for “adult” type agents);
Figure 11. The virtual model of the analyzed building

Figure 12. Location of agents within the computing field

Figure 13. Input data for the agent movement model

The movement of agents inside the building is shown in Figure 14. The times when the first and the last person left the building are presented in Table 1:

|                           | “real” evacuation drill | “virtual” evacuation drill |
|---------------------------|-------------------------|----------------------------|
| The time when the first person left the building [s] | 40                      | 45                         |
| The time when the last person left the building [s]  | 88                      | 92                         |

Table 1. Characteristic times of the human evacuation process
The graphs presented in Figure 15 show the variation in time of the number of people inside the building.

![Figure 14. Agents movement inside the building](image)

Figure 14. Agents movement inside the building

After the comparative analysis of the results from the “real” and the “virtual” evacuation drill, it can be seen that the FDS+Evac software can approximate with a high degree of credibility the movement and behaviour of persons during an evacuation drill.

5. Comparative analysis of “real” vs. “virtual” evacuation drill

A conclusion of the comparison between the results obtained in the numerical analysis and in the in-situ experiment, is that there is a trend of results convergence: the time of evacuation in approximately the same (92 s for the numerical analysis and 88 s for the “real” evacuation drill), the movement of agents, from the software, is similar to the real movement of people in choosing the escape routes. It can be noticed that there is no turbulence in both situations: of numerical simulation and in-situ experiment.

The analysis of the differences between the evacuation times in the two situations, expressed in percents, shows that there is an increase of 12.5 % in the numerical simulation for the time when the first person has been evacuated and in increase of 4.5% in the numerical simulation, for the time when the last person has been evacuated.
FDS+Evac was tested by its developers only in small groups of people [3]: less the 100 individuals. It is possible that in case of a greater number of people the modelled situation does not coincide with reality. For this reason, we must avoid extrapolating the results from the situation where we operate with a small group of people (tens) to the situation where we operate with a large or very large number of people (hundreds or thousands).

The second situation, that of large groups of people, can be the subject of an in-depth, possibly parameterized study, in which the number of people is increased successively (in example: 50, 100, 150, 200, etc.), then the interpretation of the results will be performed by observing whether there is convergence or divergence. In this case the problem must be solved independently.

A detailed study, correlated with reality, is required when the FDS+Evac is significantly qualitatively influenced by the number of people with whom it operates. In this context, by qualitative it is understood the choice of other escape routes or the mode of completion the evacuation (as example: the number of deceased persons in the case of a fire). A quantitative difference is expected to increase the evacuation time.

6. References

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Acknowledgement

The authors are grateful to Thunderhead Engineering Consultants Inc. USA for providing the free education licence for PyroSim – graphic user interface for FDS and FDS+Evac.