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Dependence of the human flow density from the staircase and exit width

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Abstract. The article studies the dependence of the human flow density on two main parameters: the width of the staircase and the number of people on the floor. It was established that violation of standards in terms of the entrance door width and the presence of a stair hall have a strong influence on the total time of evacuation due to the formation of clusters. The tabular dependence of the maximum human flow density on the staircase width on the number of people per floor was obtained. On the basis of this dependence, the graph was built, which can be used in the stair width design, taking into account the allowable human flows density in the case of known average number of people on each floor of the building.

1 Introduction

Nowadays, there is a negative tendency to thoughtlessly close the various gross violations of regulatory fire safety requirements by fire risks calculation during the building construction, especially commercial objects (business centres, shopping and entertainment complexes). These buildings are concentrators of large human clusters, therefore additional requirements should be placed on them in terms of space-planning decisions [1], fire safety of structures [2–5] and measures of their additional fire protection, as well as control of its application [6-12]. The important part is also the process of organizing evacuation, including a phased one [13-15]. During evacuation, the largest people clusters form at the stair exit points and outside exit [16, 17]. Prolonged exposure of places with the human flow density exceeding 7-8 people per m^2 can cause some various injuries, fainting, and compression asphyxia. Many regulatory rules describe the measures that are likely the most rational decisions for fire safety organization at the facility. Some of them are written taking into account not only the possibility but also the comfort of carrying out the evacuation people. This study could help to the further improvement of the regulatory rules in terms of minimum width permission of the staircases, paying attention to the dependence on the people per floor number.

The purpose of the article is to show the influence of the width of the staircases and input group parameters on the evacuation efficiency.

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2 Methods

The calculations of the evacuation time and the human flow density were made in PC Pathfinder. The program algorithm is based on an individually–streamed motion model [18, 19], which takes into account the possibility of manoeuvring and movement slowing down. Since there is no the human flow separation into stages (phases) at simultaneous evacuation, the density of the human flow after some time becomes uniform along the evacuation way. We accept that after the last person exits from the floor to the staircase, the flow moves with a constant maximum density over time. In connection with the foregoing, the modelling of a high-rise or multi-storey building does not make sense. For clarity, we model the 7-storey building and consider the evacuation of single staircase part of the building. The evacuation time was calculated during the movement on the stairs. The time step is 0.025 seconds.

Fig. 1. The simulated building.

In the calculations, we consider the maximum of the human flow density on the staircase with dependence of the staircase width and the number of people evacuating from the floor.

The width of the staircase is taken with 150 mm increment from the minimum allowable: 900, 1050, 1200, 1350, 1500 mm.

The people number for each floor is taken with 5 person increment 10, 15 ... 60. The minimum limit of this interval describes the small commercial objects in the morning or night hours. Also under this distribution of the human density are residential buildings. The maximum border is evacuation from shopping or business centers during the hours of the greatest fullness.

The following criteria for assessing the human flow density are adopted:

1. 0–2.9 people per m^2 – excellent. Identification color is blue;
2. 3.0–4.9 people per m^2 – good. Identification color is green;
3. 5.0–6.9 people per m^2 – satisfactory. Identification color is yellow;
4. 7.0–8.0 people per m^2 – unsatisfactory. Identification color is red;

The program considers the cluster impassable with a density of more than 8 people per m^2, and the simulated person waits for the possibility to continue the movement after the density reducing.

Firstly, we consider the negative scenario with rule violation in part of the staircase hall and the width of exit door.

3 Results and Discussion

The results in tables 1 and 2 are based on the simulation and present the maximum flow density during movement on the staircase and the estimated evacuation time.

Table 1. Maximum density of human flow.

Human flow density, people per m^2		Number of people per floor, pcs										
		10	15	20	25	30	35	40	45	50	55	60
Staircase width, mm	900	3.2	4.0	4.8	5.6	6.4	7.2	7.2	7.4	7.6	7.6	7.6
	1050	2.4	2.8	3.6	4.8	6.0	6.8	7.8	8.0	8.0	8.0	8.0
	1200	2.4	2.4	2.8	3.6	4.8	5.8	6.8	7.2	7.4	7.6	7.8
	1350	2.0	2.2	2.8	3.2	3.6	4.8	5.6	6.6	7.2	7.4	7.8
	1500	1.8	2.2	2.6	3.0	3.2	3.8	4.8	5.6	6,4	7.0	7.2

Table 2. Estimated time of evacuation.

Time, sec		Number of people per floor, pcs										
		10	15	20	25	30	35	40	45	50	55	60
Staircase width, mm	900	84.5	98.0	117.8	143.3	166.5	190.8	214.5	241.0	261.5	288.0	316.0
	1050	85.3	95.3	110.0	130.3	156.0	179.0	205.5	230.0	258.5	284.0	308.8
	1200	83.8	92.3	110.3	134.0	156.5	180.0	204.8	232.0	253.3	275.0	310.0
	1350	82.3	91.8	107.0	127.0	156.0	182.0	203.3	229.5	253.0	278.3	306.3
	1500	81.9	91.6	106.0	130.3	152.5	180.5	204.8	233.4	256.1	278.8	309.3

The table 2 analysis shows that the evacuation time remained actually constant regardless of the staircase width, while the flow density has a significant change dynamic. Such a result distribution should appear only in case of few people evacuating, whereas with an increase in the people number on the floor, the stair width should play a decisive role in calculating the evacuation time.

The analysis of the computational model showed the presence of two factors that directly affect on the evacuation process and its results.

1. Due to the lack of a staircase hall, the exit to the outside was located very close to the exit from the staircase. This led to the formation of large crowds of people at the exit from the staircase, which prevented free movement out (Fig. 1).

The isofield of the human flow density in the absence of the hall recorded the achievement of unsatisfactory values. The extra space has reduced the flow density at the outlet to excellent values.

2. The width of the exit door on the first floor. Insufficient width contributes to the formation of extra clusters.

To determine the required width of the doorway, we carry out the maximum human number on the floor (60 people) and the largest of the considered staircases (1500 mm) – extreme case in 2 parameters (Table 3).

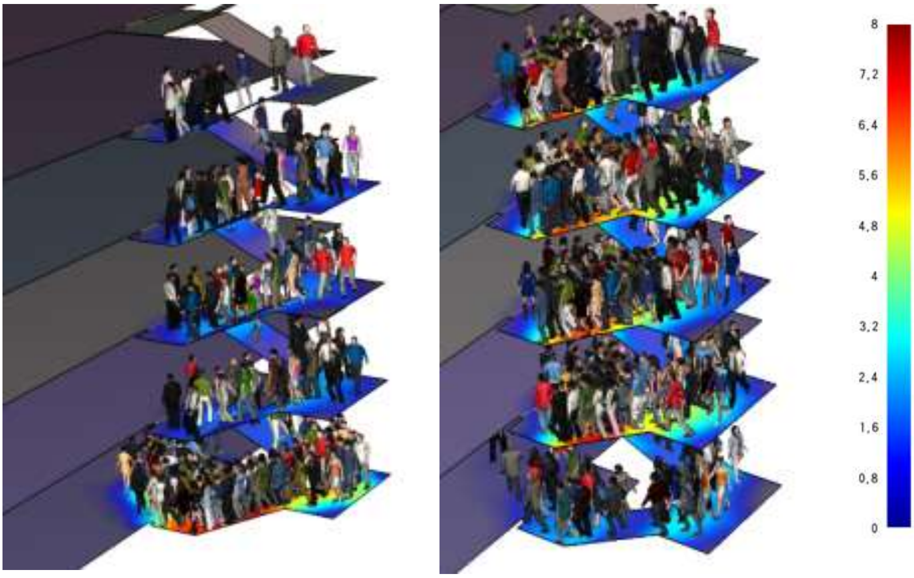

Fig. 1. The isofield of the human flow density with dependence on the presence of the hall a) there is no hall, b) there is a hall..

Table 3. Estimated evacuation time depending on the outer doorway width.

Doorway width, mm	Evacuation time, sec
1000	292.0
1100	271.8
1200	251.3
1300	228.5
1400	216.3
1500	205.0
1600	203.5
1700	203.0

There is no decrease in the estimated evacuation time after the 1500 mm door width, so an external doorway of 1500 mm was adopted for re-modeling. The following results were obtained with corrected the negative factors (table 4 and 5).

Table 4. Maximum density of human flow with corrected negative factors.

Human flow density, people per m^2		Number of people per floor, pcs										
		10	15	20	25	30	35	40	45	50	55	60
Staircase width, mm	900	3,2	4.0	4.8	5.6	6.4	7.2	7.2	7.4	7.6	7.6	7.6
	1050	2.4	2.8	3.6	4.8	6.0	6.8	7.6	7.8	8.0	8.0	8.0
	1200	2.4	2.4	2.8	3.6	4.8	5.6	6.6	7.0	7.4	7.4	7.6
	1350	1.8	2.2	2.8	3.2	3.6	4.6	5.4	6.6	7.2	7.4	7.6
	1500	1.8	2.2	2.6	3.0	3.2	3.8	4.4	5.0	5.8	6.6	7.0

The graph is based on dependence between the human flow density and the people evacuating number for each considered staircase (Fig.2).

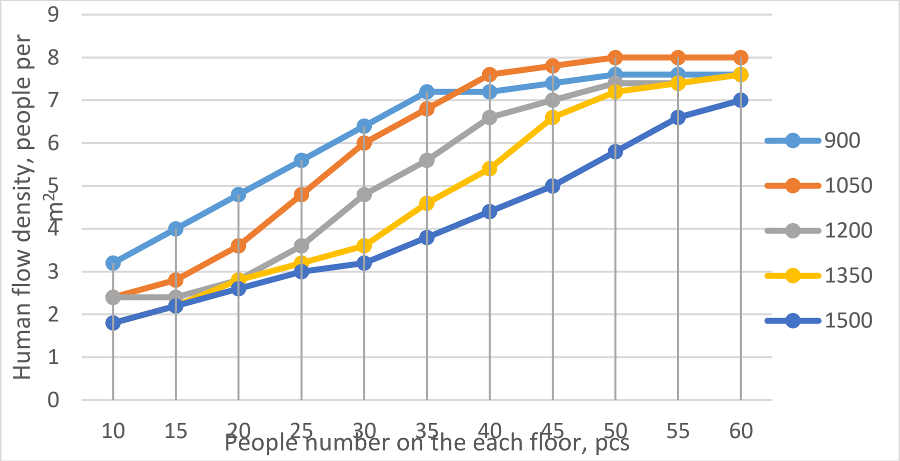

Fig. 2. Dependence of the human flow density on the number of evacuating people.

The lower flow density and the lack of graph increasing for the 900 mm staircase are explained by the program algorithm peculiarities. The PC Pathfinder does not allow the clusters formation more than 8 people per m^2, so people in that version actually "wait" for their turn and do not go forward. This is obviously demonstrated by a noticeably larger slope of the evacuation time graph for this staircase width (Table 5). This schedule can be used to design the width of staircases with a known average number of people on each buildings floor.

Table 5. Estimated time of evacuation with corrected negative factors.

Time, sec		Number of people per floor, pcs										
		10	15	20	25	30	35	40	45	50	55	60
Staircase width, mm	900	86.0	98.8	120.8	142.8	169.5	192.5	217.8	243.5	265.3	287.8	312.5
	1050	85.8	97.3	110.3	132.5	149.5	169.8	191.0	210.3	234.0	251.8	273.5
	1200	87.5	94.5	103.3	120.5	137.5	154.8	172.3	188.8	210.8	225.0	243.3
	1350	85.3	95.0	101.0	111.8	125.5	142.3	157.5	172.8	191.5	204.8	220.0
	1500	85.3	94.3	103.5	109.5	118.3	133.3	146.3	161.3	174.5	188.5	205.0

The negative factors (staircase hall and the outer door width) had a small effect on the final flow density (Tables 1 and 4). However, this was crucial for the estimated evacuation time (Table 6).

Table 6. The percentage change in the estimated evacuation time with corrected negative factors.

Time, sec		Number of people per floor, pcs										
		10	15	20	25	30	35	40	45	50	55	60
Staircase width, mm	900	-1,8	-0,8	-2,5	0,3	-1,8	-0,9	-1,5	-1,0	-1,5	0,1	1,1
	1050	-0,6	-2,1	-0,3	-1,7	4,2	5,1	7,1	8,6	9,5	11,3	11,4
	1200	-4,4	-2,4	6,3	10,1	12,1	14,0	15,9	18,6	16,8	18,2	21,5
	1350	-3,6	-3,5	5,6	12,0	19,6	21,8	22,5	24,7	24,3	26,4	28,2
	1500	-4,2	-2,9	2,4	16,0	22,4	26,1	28,6	30,9	31,9	32,4	33,7

We assume that the percentage change results, which are less than 5% in relative and 10 seconds in absolute values, are the error within the simulation. Analysis of the estimated time changes shows that the influence of the both negative factors depends on the two complex parameters: the stair width and the people number on the floor. The influence of the correct door width and the staircase hall presence is growing with the increase of one of considered parameters.

4 Conclusions

The article shows the influence of the staircase hall presence in front of the entrance door and the doorway width on the human flow density and the estimated evacuation time. The final density has changed a little from the original, but the estimated evacuation time has changed dramatically (up to 30% of the initial). This is due to the cluster absence before the exit and the possibility of unhindered movement. The tabular dependence of the maximum human flow density on the staircase width on the people number per floor was obtained. On the basis of this dependence, the graph is built, which can be used in the stair width design, taking into account the allowable human flow density in the case of known average people number on each floor of the building.

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