Problems of Regulating the Safe Evacuation of People at the Subway Stations

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Abstract. This article describes the main provisions for assessing the safety of people during the evacuation from the subway stations. A huge number of passengers waiting for the train, leads to a seal flow. The high-density value reduces the width of the doorway in the light. People tend to enter the car without waiting for the passengers to leave it, being afraid not to have time to land in the allotted time for this or not to get into the car as a result of its overfilling. Higher intensity values can be observed in the case of a small number of waiting passengers. The density of people on the platform when waiting for the train determines, in addition, the comfort of the waiting conditions of passengers and their safety. The presented results of the study on the safety of subways will allow more accurately and differentially determine the movement of human flows in the different sections of the track at the metro stations.

1. Introduction

According to the Town Planning Code of the Russian Federation (Part 1, article 48.1) [1] subways are considered to be particularly dangerous, technically complex facilities. Therefore, the safety of people in pedestrian subway structures (stations and interchange nodes) should be determined by calculation based on an assessment of individual fire risk, according to the Federal Law of the Russian Federation of 22.07.2008 No.123-FZ "The technical regulation about requirements of fire safety"[2]. The requirements of SP 120.13330.2012 "Subways" [3] also comply with this concept, that sufficiency of design decisions to ensure the safe evacuation of people at the station must be estimated by calculation, and when calculating the evacuation time, all protected escape routes are taken into account. Further, paragraph 5.4.1.3 indicates that the length of the no-break sections at the ends of the landing part of the platforms of the deep-laying station should be taken no more than 1/3 of the length of the landing platform and determined from the conditions that the passengers should be released from this section during a period not exceeding the minimum interval between by trains and within the estimated time of evacuation of passengers from the station. However, neither SP 120.13330.2012 "Subways", nor methodology for the determining the estimated values of fire risk in buildings, structures and structures of various classes of functional fire hazard [4] give the calculated values of the parameters necessary to determine the probability of the evacuation.
2. Methodology

2.1. Evacuation routes and exits

The paragraph 5.16.6.3 of SP 120.13330.2012 "Subways" indicates that the following routes should be provided for evacuation from the platform halls of the station:

1. Along escalators and (or) stairs of the 2nd type, corridors, through the cash rooms of the lobby, underground passages - until they exit;
2. Through interchange facilities - to the station of another line and further as in point "1", thereby expanding the concept of escape routes and exits.

2.2. Estimated fire hazardous situation

The SP 120.13330.2012 "Subways" does not establish the design situation for determining of sufficiency of design decisions to ensure the safe evacuation of people at the station. A possible place of occurrence of a fire source may be a household or industrial premises, one of the rooms for the movement of passengers, a wagon moving in a train tunnel. The paragraphs of SP 120.13330.2012 "Subways" establish:

- The paragraph 5.16.6.1: "... In the event of a fire in one of the wagons of a train moving in a tunnel, it must continue to move to the nearest station to evacuate people and extinguish the fire";
- The paragraph 5.16.6.4: "When equipping rolling stock elements (carriage equipment, hardware compartment, driver’s cab) with an automatic fire extinguishing installation, fire-fighting is carried out while the train is moving. Moreover, the evacuation of passengers is carried out after the arrival of the train at the station".
- As a calculated fire hazard situation, a fire should be taken in one of the train cars located at the station.

2.3. Estimated evacuation scheme

The paragraphs of SP 120.13330.2012 "Subways" require:

- The paragraph 5.16.6.17: "... The estimated number of people (including MGN) in the station facilities must be determined based on the maximum prospective passenger flows of the designed station and the conditions that trains follow the non-emergency path without stopping at the station with fire (to the passage)"
- The paragraph 5.16.6.18: "To ensure the safe evacuation of people in case of fire, when the fire alarm system is activated, turnstiles must be unlocked with free movement of people in both directions"
- The paragraph 5.16.6.2: "From the platform halls of the station, at least two dispersed evacuation exits should be provided, ensuring safe evacuation of people in case of fire"

The ability to block one of the evacuations exits of the platform hall of the station determines the unidirectional movement of human flows during evacuation. Sources of human flows are exits from burning cars and station platforms with passengers on them waiting for the arrival of the next train.

The estimated number of evacuated is determined by the maximum congestion during peak hours and the congestion of both station platforms by waiting passengers. The design evacuation scheme has a general view, presented on Figure 1.
2.4. Features of the movement of human flows in areas in the estimated evacuation scheme

The features of the movement of human flows in areas in the estimated evacuation scheme include:

- exit of people from cars;
- flow formation on the platform;
- expanding flow on a section of a common path;
- the movement of human flows in areas in front of escalators associated with the functioning parameters of escalators;
- the movement of human flows through automatic checkpoints.

The description of these features required specially organized field observations [5-19], the full complex of which was first performed by the video method [6, 7, 20] on Figure 2.

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**Figure 1.** The estimated evacuation scheme.

**Figure 2.** The example of conducting field observations using the method of video observations with the construction of a computational grid: 1 - the first section (horizontal path); 2 - second section (horizontal path between the guiding devices); 3 - third section (horizontal path between balustrades); 4 - the fourth section (comb); 5 - the fifth section (escalator tape).
2.5. People leaving from the metro coaches

The need to study human flows on the platform of the metro station is associated with the performance of two functions:

- the formation of the people leaving from the metro coaches,
- accumulation of passengers while waiting for the train.

The field observations of the movement of people on the platform were carried out at "Turgenevskaya" Moscow metro station under normal operating conditions of the metro and during "peak" hours.

The values of the intensity of the people leaving from the metro coaches are presented in Table 1.

| Observation period | Number of observations | Intensity, q people / m min | Dispersion, S^2 people^2 / m^2 min^2 |
|--------------------|------------------------|-----------------------------|--------------------------------------|
| Summer             | 125                    | 49.2                        | 118.02                               |
| Winter             | 119                    | 51.13                       | 161.93                               |

The above results indicate that there is no influence of the time of the year on the intensity of people leaving from the metro coaches.

2.6. People flow formation on the platform

A large number of passengers waiting for the train, leads to a seal flow. The density of people in front of the car door when the train approaches reaches 5 people/m^2. A high-density value reduces the width of the doorway in the light. People tend to enter the car without waiting for the passengers to leave it, being afraid not to have time to land in the allotted time for this or not to get into the car as a result of its overfilling. Higher intensity values can be observed in the case of a small number of waiting passengers.

The density of people on the platform when waiting for the train determines, in addition, the comfort of the waiting conditions of passengers and their safety. The density value should be taken into account when determining the area of the "waiting zone" of the station platform. After people exit the cars and from the platform to the distribution room of the metro station, the width of the human flow increases [6,9-13, 18], the so-called "expansion" of the flow (Figure 3).
The reason for the formation of "expanding" human flows is the desire of participants to go with a lower density, which allows to increase speed and increase comfort of movement. Each person seeks to reduce the time spent on movement, and this can be achieved in two ways: the first is an increase in the speed of movement, which occurs due to a decrease in the flux density; the second is the reduction of the path length. The latter is the reason that the human flow stops expanding due to the deviation of the trajectories of movement from the shortest direction. The stabilization of the width of the flow occurs when it reaches a certain value of its density, at which a certain equilibrium is established between the density, speed and path length.

The obtained probability distribution of the density values of “expanding” flows is shown on Figure 4.

![Figure 4](image)

**Figure 4.** The density distribution approximation of the expanding flows by the normal law of distribution:

- histogram of statistical distribution;
- statistical distribution latitude;
- theoretical distribution curve.

The regularity of the relationship between the speed and density of the human flow [8,15] is described as an elementary random function:

\[
V_D = V_0(1 - a \ln \frac{D}{D_0})
\]

where \(V_D\) is the value of the random variable velocity at the flux density \(D\), which depends on the type of path and on the psychological tension of the movement process; \(V_0\) is a random value of the flow velocity at a flux density lower than \(D_0\); \(D_0\) is the threshold value of the density, upon reaching which it becomes a factor that affects the speed of people in the stream.
As can be seen, the values of the coefficient for both types of motion are very close. Since in both cases the movement occurs along a horizontal path, it is legitimate to accept a single coefficient value equal to the average value. It amounted to $a = 0.3997 \approx 0.4000$.

2.7. *The movement of people flows in areas in front of escalators*

Based on the results of field observations, conclusions were drawn that the speed of the escalator bed affects the parameters of the movement of the human stream. An increase in the velocity $V$ and the intensity of movement $q$ at the same flux density with a decrease in the velocity of the escalator to $V_c = 0.74 \text{ m/s}$ and a decrease in $V$ with a further decrease in $V_c$ were recorded.

Attention is drawn to the identity of changes in the parameters of the movement of the human flow when the velocity of the escalator bed deviates both to a smaller and a larger side from the value of $V_c = 0.74 \text{ m/s}$. So, for example, the parameters of the movement of people at $V_c = 0.56 \text{ m/s}$ are close in their values to the parameters of movement at $V_c = 0.84 \text{ m/s}$. This pattern is explained by an increase in the concentration of people in front of the escalator with an increase or decrease in the speed of the canvas. At small and large values of $V_c$, the cluster spread over almost the entire length of the visible section of the path.

How quickly the transition through the comb will occur, whether a movement delay occurs and how long it is, depends on how much the approach speed $V_a$ differs from the speed of the escalator $V_c$:

$$q(V_c) = -a(V_c - V_a)^2 + q_{\text{max}}.$$  \hspace{1cm} (2)

3. *Results and discussions*

The results of the field observations showed that the carrying capacity of the escalator $Q_c$ increases with an increase in its speed to $0.7 \text{ m/s}$, and then it decreases. The reason is that at an escalator speed of $V_c = 0.7 \text{ m/s} = 42 \text{ m/min}$, the difference between $V_a$ and $V_c$ is minimal, this ensures the greatest value of the carrying capacity of the escalator.

The approximation of the dependence of the carrying capacity of the escalator on the speed of movement of his canvas is determined by the formula:

$$Q(V_c) = 60\{19.6 + [-0.028(V_c - 42.37)^2]\}/f, \text{ man/hour}$$ \hspace{1cm} (3)

Field observations [5, 6, 9, 14, 16, 17] of the movement of people flows through automatic checkpoints during peak hours under normal operating conditions with flux densities in front of them from 1 to 5 people / $\text{m}^2$ show that their transit time $(t_{pr})$ depends from the tension of the movement process. At $D = 2$ people / $\text{m}^2$, the value of $t_{pr}$ under normal conditions, due to an increase in traffic intensity, approaches the value of $t_{pr}$ during peak hours (Figure 5).
Figure 5. The dependence of the transmission capacity of the automatic transmission on the density of people flow in front of them.

4. Conclusions

The stated research results provide the necessary prerequisites for the development of the code of rules "Fire safety of subways" and the development of the methodology for determining the calculated values of fire risk in buildings, structures and structures of various classes of functional fire hazard [4], which will make it possible in the future to more accurately and differentially determine the parameter \( P_e \), taking into account the movement of people flows through different sections of the track at metro stations and to develop reasonable fire-fighting measures.

References

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