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Questioning the linear relationship between doorway width and achievable flow rate

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ABSTRACT

This paper challenges the currently assumed linear relationship between doorway width and achievable flow. The current view is seen as a simplification that may lead to an overly optimistic view of the achievable flow rates. Analyzed data are presented in order to demonstrate the impact that the actual use of the doorway and its design can have upon the flow rate generated. These data are then supported by the use of numerical simulations to demonstrate the impact that this overestimation can have upon the design process. It is contended that the specific flow rate assumed for a doorway should take into consideration not only its width, but also the design of the doorway (i.e., the opening and closing mechanism) and how evacuees behave in response to it. The issues raised have implications for the governing codes/regulations, engineering guidance and on the development of future computational egress models.

1. Introduction

Egress calculations are often used to assess the expected performance of a specific egress arrangement during an emergency. Traditionally, this has required the use of equations to predict the achievable flow and the overall evacuation times. These equations are formed from empirical data collected from a number of sources, primarily non-emergency in nature [1].

Given the nature of configurational design, certain components limit the overall flow rate which can be achieved during egress movement. Some building components may have high flow capacities, while others may restrict the flow through a reduction in the space available. This is particularly evident where large numbers of people are involved in the egress movement. The assumptions made regarding these limiting components are therefore critical to the overall evacuation times predicted.

The flow rate associated with exit points is usually derived from a number of key sources [2–6]. The doorway width available is often reduced based on an assumed boundary layer; the resultant usable width is termed the effective width [5]. However, the width lost is independent of the overall width of the doorway [5]. The final specific flow rate produced is assumed to be a linear function of the effective width of the doorway and the flow rate derived from empirical data.

This paper suggests that the currently assumed linear relationship between doorway width and achievable flow is a simplification, which can lead to an overly optimistic view of achievable flow rates. Analyzed data are presented to demonstrate the impact that the actual use and the type of doorway can have upon the flow rate. These data are supported by the use of numerical simulations to demonstrate the impact this overestimation can have upon the design process.

This paper argues that the specific flow rate assumed for a doorway should take into consideration not only its width, but also its design (i.e. the opening mechanism) and how evacuees behave in response to it. The issues raised can have implications for governing codes/regulations, engineering guidance, and on the development of future computational egress models.

2. Recommended engineering approach

We will briefly describe the engineering approach presented in the Society of Fire Protection Engineers (SFPE) Handbook [1] and

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the assumptions on which it is based. This method is selected as it is the most widely applied engineering technique. As with all of the hydraulic approaches, they are sensitive to the flow rates assumed within the calculations. This is particularly the case when examining high-density situations where the overall evacuation time is dependent upon the congestion produced, as opposed to the distances traveled.

2.1. SFPE handbook

Nelson and Mowrer [1] derived a descriptive system of movement based on the work of Fruin [2], Predtechenskii and Milinskii [3], and Pauls [4,5]. At the time of the development of this approach, this research represented the most detailed and respected data available. Nelson and Mowrer's work is based upon the assumption that the speed of an individual is dependent upon the population density. In turn, the density of the population and the speed at which the population is traveling determine the flow rate. The hydraulic method adopted is based on the following assumptions: that the population evacuates simultaneously, providing a reservoir of people to ensure the assumed flow rates; occupant decision-making will not interrupt the flow produced; and the flow is not significantly influenced by the presence of the disabled, or the movement impaired, with the population traveling at uniform speeds.

This engineering approach is dependent on a number of key terms: population density (occupants/m^2 or occupants/ft^2); velocity (m/s or ft/min); effective doorway width (m or ft); and specific flow rate (occupants/m/s or occupants/ft/min). These terms are employed to determine the time taken to reach particular components and then the time taken to move through a congested area.

The speed of movement, S, for an occupant density, D, between 0.54 and 3.8 occupants/m^2 (0.05 and 0.35 occupants/ft^2) can be determined by the relationship

$$s = k - akD$$

where a and k are constants whose values vary according to the component and the units used. Speed is therefore linearly related to density, and this equation becomes

$$(\mathrm{m/s})\ S = 1.4 - 0.37D$$

$$(\mathrm{ft/min})\ S = 275 - 786.5D$$

The specific flow, F_s, can be determined through the following expression

$$F_s = SD = k(D - aD)^2$$

Fig. 1 shows a graphical relationship between F_s and D for the case of a doorway.

Finally, the calculated flow rate F_c (occ/s) is established by multiplying the specific flow by the effective width of the doorway, W_e:

$$F_c = F_s W_e$$

Based on the calculations above, the maximum value of specific flow rate which can be achieved for a doorway is 1.3 occupants/m of effective width/second (24.0 occupants/ft of effective width/min). These maximum values (see Table 1) are often used in engineering calculations as the default value given that congestion is assumed, especially where the evacuation is dominated by the population size and density, rather than the distances which have to be traversed. Even though the specific flow rate is different for various exit route elements, it should be emphasized that the engineering approach described does not differentiate among the achievable flow rates of several different components (e.g. door-

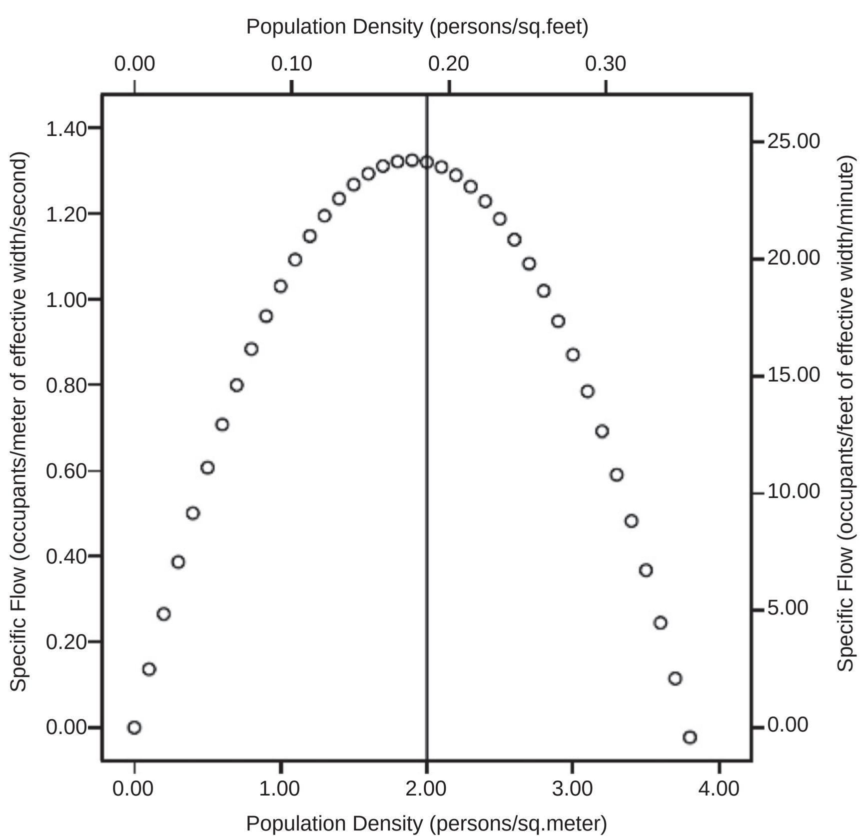

Fig. 1. Specific flow rate for the doorway/corridor/aisle/ramp as a function of density, redrawn from original [1].