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On Critical Densities And Velocities For Pedestrians Entering a Crowd

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Abstract

The problem of pedestrians trying to enter and/or advance against an incoming crowd is studied. The analysis shows that starting with a very limited set of assumptions (elliptical cross-section of pedestrians; constant ratio of forward to lateral separation) one is able to derive from purely kinematic considerations critical densities beyond which it is impossible for pedestrians to enter and/or advance into an incoming crowd. The results obtained indicate that for the common pedestrian size of $a = 0.5\ m,\ b = 0.3\ m$, the limit densities range from $\rho = O(5.0 - 6.06)\ [p/m^2]$, in good agreement with empirical observations.

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1. Introduction

In many situations, pedestrians need to enter a moving crowd. Subway and train stations, airports, sports events, mass concerts and other venues with large crowds are familiar examples. Perhaps the worst case for a pedestrian trying to enter and pass through the moving crowd is shown in Figure 1. The limiting cases are obvious: for low crowd densities and speeds the motion of the incoming pedestrian is basically unimpeded; for very high crowd densities or velocities it may result impossible for the incoming pedestrian to enter and/or advance against the crowd. Clearly, there must be a so-called **critical density and velocity relation** beyond which entering and moving against the incoming stream is impossible.

The attempt to derive such critical values stems from a very immediate need: emergency personnel may have to move against an incoming crowd. Knowing when this is possible and how long it would take to reach the scene of an accident in such a situation are requirements that building and event planners have to meet.

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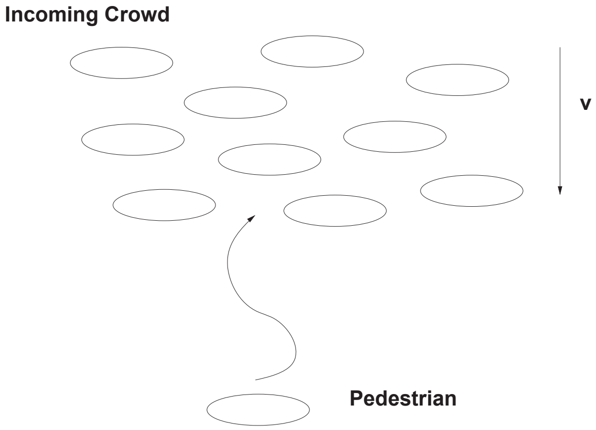

Fig. 1. Pedestrian Trying to Enter an Incoming Crowd

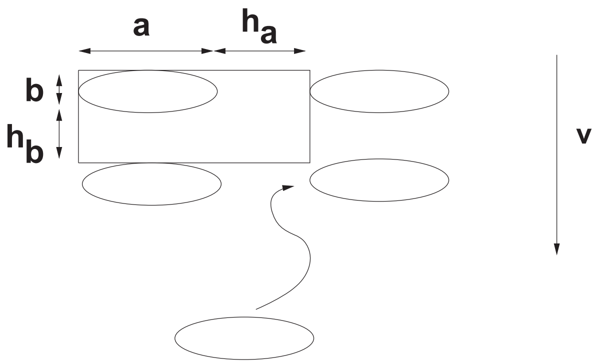

Fig. 2. Pedestrian Dimensions and Row Formation

2. Limiting Densities for Entering a Stationary Crowd

In order to fix the ideas and notation, let us consider pedestrians that have an elliptical cross-section of dimension $E = a \cdot b$ (see Figure 2).

Furthermore, in order to obtain a scenario that is easy to analyze, let us consider the case where the incoming crowd is in row formation as shown in Figure 2. The distances between pedestrians are assumed to be h_a, h_b respectively. Each pedestrian of the crowd then occupies an area of $A = (a + h_a)(b + h_b)$, implying that the density is given by:

$$\rho = \frac{1}{(a + h_a)(b + h_b)} \ \ [p/m^2] \ . \tag{1}$$

Just to verify: for the typical values of $a = 0.5\ m, b = 0.3\ m$ the limit density ($h_a = h_b = 0$)

$$\rho_l = \frac{1}{ab} \tag{2}$$

is given by: $\rho_l = 6.67\ p/m^2$. Note that this is below the absolute limit density given by

$$\rho_l^a = \frac{4}{\pi ab} \tag{3}$$

which yields $\rho_l^a = 8.49\ p/m^2$, in line with empirical observations (Predtetschenski and Milinski (1971)).