Effects of the body force on the evacuation dynamics

Abstract

Keywords:
Pedestrian Dynamics, Social Force Model, Body Force
PACS: 45.70.Vn, 89.65.Lm

---

1. Introduction

The Social Force Model (SFM) addresses two physical forces as *essential*: the "body force" and the "sliding friction". Both are inspired by granular interactions and were claimed to be necessary for attaining the particular effects in panicking crowds [1]. The "sliding friction" actually proved to be an essential feature of the "faster-is-slower" effect, although the role of the "body force" appears, at a first instance, not so clear [2, 3, 4].

The existence of a "body force" in the context of highly dense crowds (say, 5 to 10 people/m^2) is a commonsense matter [5, 6]. Researchers, however, question the numerical setting for this force in the SFM context [7]. As a matter of fact, the usual setting by Helbing prevents the overlapping among pedestrians, but it is known to accomplish artificially high force levels [1, 7, 8, 9]. The force estimates from the SFM appear to be remarkably higher with respect to the reported real life data (say, an order of magnitude). The crowd motion simulations, however, present quite realistic results [7, 8, 10]. The point seems to be that the SFM focuses on the "incoordination phenomenon" due to clogging, missing the "individualistic" perspective of single pedestrians or very small groups [1, 5, 11].

Many researchers realized that modifying the SFM may (partially) surpass the misleading parameter setting. It was proposed that the pedestrians' psychological force (say, the "social force") should be suppressed in the context of highly dense crowds [12, 13, 14, 15], or smoothly quenched according to the crowd density [16]. The authors in Refs. [17, 18] further proposed a rigid body model in order to completely avoid the overlapping phenomenon. This perspective dismisses any connection to a "sliding friction". Conversely, other authors tried to limit the pedestrians acceleration by introducing "static friction" between the pedestrians and the floor [19]. This kind of friction, however, reduces the effective willings of the pedestrians.

A meaningful (individualistic) numerical setting appears not available yet (to our knowledge). The reason is that different numerical settings can lead to the same crowd dynamics. Actually, only a small set of dimensionless "numbers" control the crowd dynamics [20]. These are similar to those encountered in other active matter systems (Péclet number, etc.) [21]. We may hypothesize that while the dimensionless "numbers" provide some kind of control on the "incoordination phenomenon" in crowds, only a few numerical settings can attain an "individualistic" meaning.

The numerical setting for the "faster is slower" effect presented by Helbing and co-workers is somewhat cumbersome Ref. [1, 10, 20]. Although a single parameter (say, the desired velocity v_d) is numerically varied to explain the phenomenon, the researcher looses sight of the dimensionless "numbers" that truly control the crowd dynamics. The setting in Ref. [1] also misses the "faster is faster" effect reported to occur at very high pedestrian densities [10, 22]. Alternatively, the empirical fundamental diagram raises as a point of reference for the SFM control parameters [23, 10].

The fundamental diagram exhibits the flux behavior for either low dense crowds (with seldom contacts between pedestrians) and highly dense crowds (dominated by body forces and sliding friction). The latter usually experiences a flux slowing down, but other behaviors are also possible [23, 24]. In light of our previous hypothesis, we may suspect that the modeling of the "flux slowing down" within the context of the SFM will require the proper setting of the (dimensionless) controlling parameters. We examined this working hypothesis in Ref. [20], but limiting the parameter exploration to the sliding friction, disregarding the body force.

We now widen the investigation on the parameter settings to include the one associated to the body force. We will focus on the complex interplay between the body force and the sliding friction among pedestrians. Recall that the interplay dynamics is not directly controlled by the numerical setting, but through dimensionless “numbers”, where the model parameters appear mixed between each other. Thus, this step up offers a challenge to the “individualistic” meaning of the parameter's setting.

The investigation is organized as follows. We first recall the available experimental values on the body force and the sliding friction (see Section 2). Secondly, we introduce the reduced-in-units SFM and the three dimensionless numbers that control the crowd dynamics (see Section 3). We present our numerical simulations in Section 4. For the sake of clarity, this Section is separated into two major parts: the bottleneck scenario and the corridor scenario in Sections 4.1 and 4.2, respectively. Section 5 opens a detailed discussion raising from of the results in Section 4. The last Section closes the investigation with our main conclusions.

2. Experimental background

3. Theoretical background

3.1. The Social Force Model

4. Results

4.1. Bottleneck

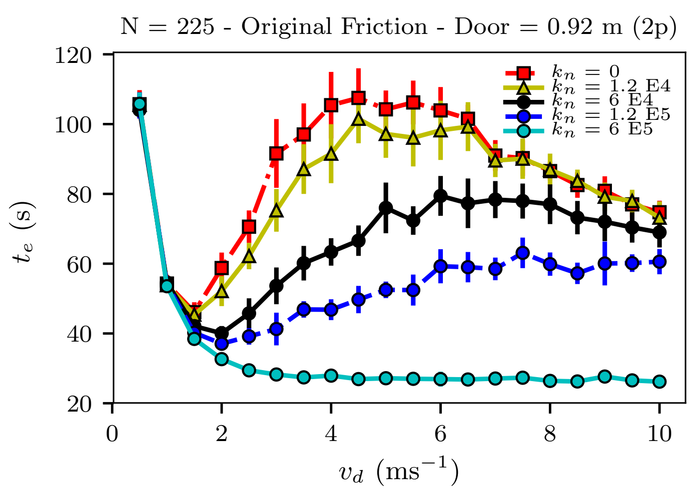


Figure 1:

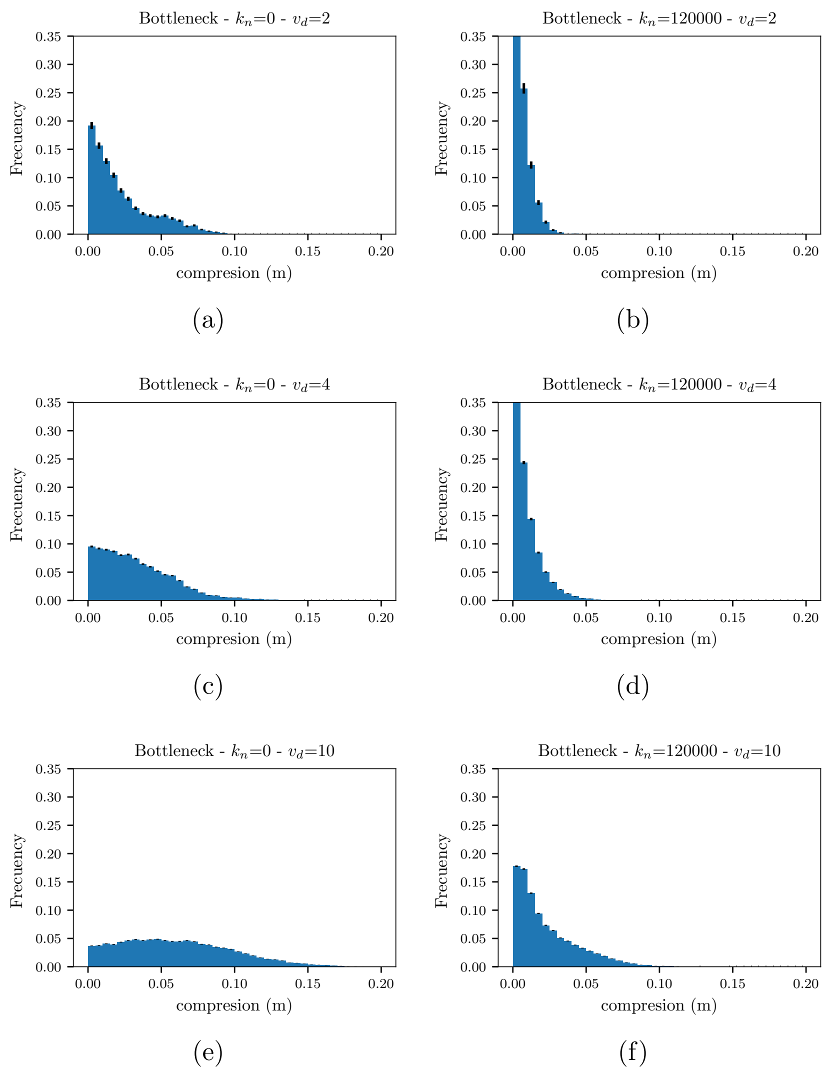
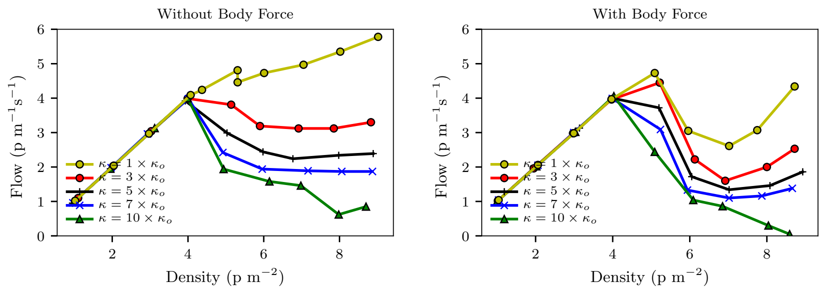

Bottleneck - k_n=0 - v_d=2
Frecuency
compresion (m)
(a)
Bottleneck - k_n=120000 - v_d=2
Frecuency
compresion (m)
(b)
Bottleneck - k_n=0 - v_d=4
Frecuency
compresion (m)
(c)
Bottleneck - k_n=120000 - v_d=4
Frecuency
compresion (m)
(d)
Bottleneck - k_n=0 - v_d=10
Frecuency
compresion (m)
(e)
Bottleneck - k_n=120000 - v_d=10
Frecuency
compresion (m)
(f)

Figure 2:



(a) (b)

Figure 3:

4.2. Corridor

4.3. Reduced-in-units equation of motion

5. Discussion

6. Conclusions

Acknowledgments

This work was supported by the National Scientific and Technical Research Council (spanish: Consejo Nacional de Investigaciones Científicas y Técnicas - CONICET, Argentina) grant Programación Científica 2018 (UBA-CYT) Number 20020170100628BA.

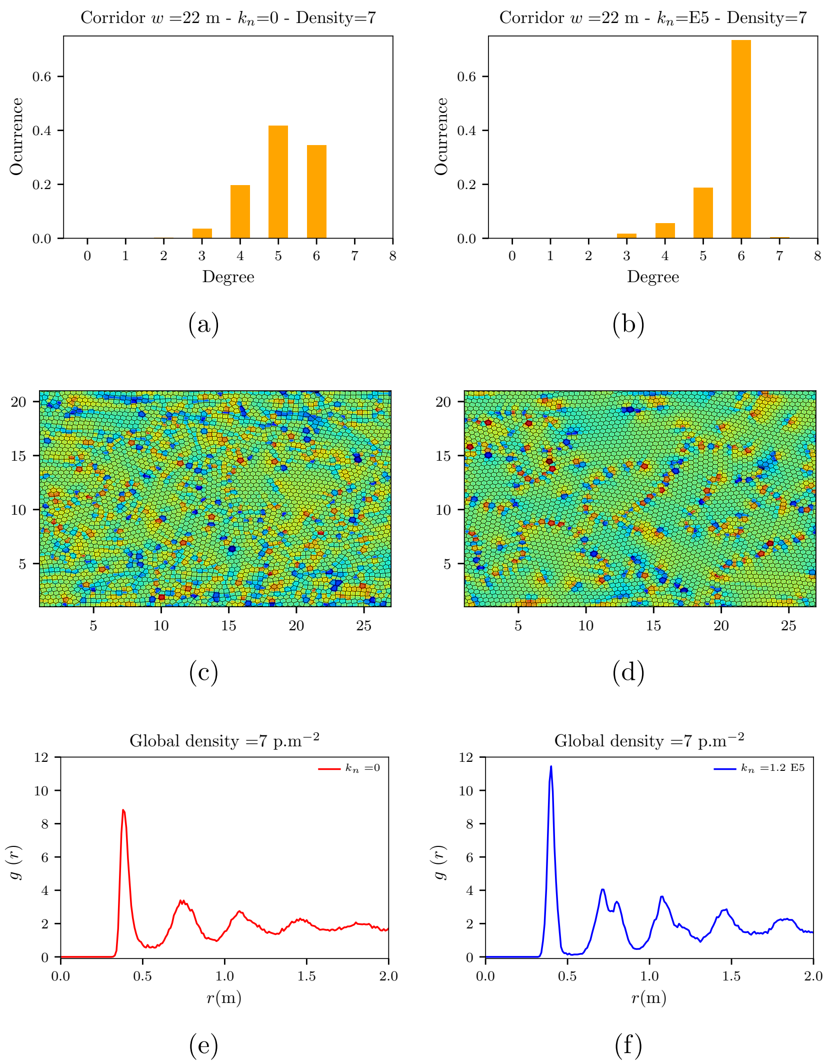
[1] D. Helbing, I. Farkas, and T. Vicsek. Simulating dynamical features of escape panic. *Nature*, 407:487–490, 2000.

[2] D. Parisi and C. Dorso. Microscopic dynamics of pedestrian evacuation. *Physica A*, 354:606–618, 2005.

[3] D. Parisi and C. Dorso. Morphological and dynamical aspects of the room evacuation process. *Physica A*, 385:343–355, 2007.

[4] G. Frank and C. Dorso. Room evacuation in the presence of an obstacle. *Physica A*, 390:2135–2145, 2011.

[5] Colin M. Henein and Tony White. Macroscopic effects of microscopic forces between agents in crowd models. *Physica A: Statistical Mechanics and its Applications*, 373:694 – 712, 2007.



Corridor w =22 m - k_n=0 - Density=7
Ocurrence
Degree
Corridor w =22 m - k_n=E5 - Density=7
Ocurrence
Degree
(a)
(b)
(c)
(d)
Global density =7 p.m^{-2}
k_n =0
$g\ (r)$
r(m)
Global density =7 p.m^{-2}
k_n =1.2 E5
$g\ (r)$
r(m)
(e)
(f)

Figure 4:

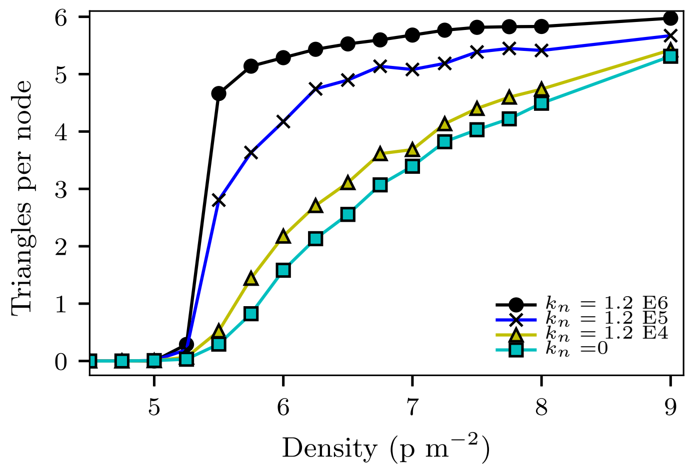


Figure 5:

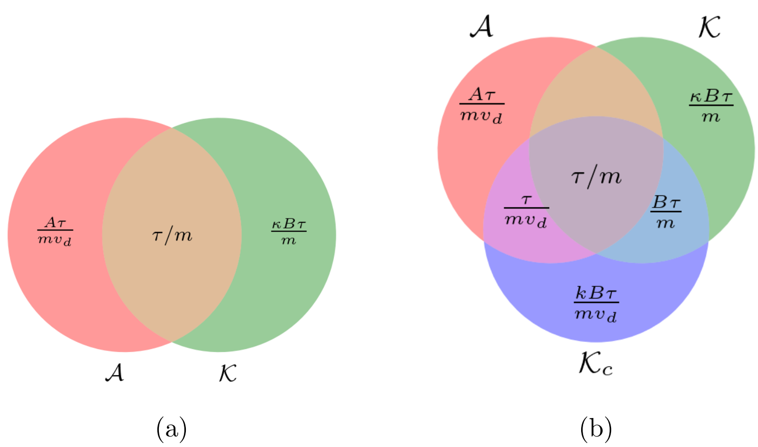


Figure 6:

[6] J. Fruin. The causes and prevention of crowd disasters. In R.A. Smith and J.F. Dickie, editors, *Engineering for Crowd Safety*. Elsevier, 1993.

[7] Taras I. Lakoba, D. J. Kaup, and Neal M. Finkelstein. Modifications of the helbing-molnr-farkas-vicsek social force model for pedestrian evolution. *SIMULATION*, 81(5):339–352, 2005.

[8] Paul A. Langston, Robert Masling, and Basel N. Asmar. Crowd dynamics discrete element multi-circle model. *Safety Science*, 44(5):395 – 417, 2006.

[9] Peng Lin, Jian Ma, You-Ling Si, Fan-Yu Wu, Guo-Yuan Wang, and Jian-Yu Wang. A numerical study of contact force in competitive evacuation. *Chinese Physics B*, 26(10):104501, sep 2017.

[10] I. M. Sticco, F. E. Cornes, G. A. Frank, and C. O. Dorso. Beyond the faster-is-slower effect. *Phys. Rev. E*, 96:052303, Nov 2017.

[11] Rahul Narain, Abhinav Golas, Sean Curtis, and Ming C. Lin. Aggregate dynamics for dense crowd simulation. *ACM Trans. Graph.*, 28(5):122:1–122:8, December 2009.

[12] N. Pelechano, J.Allbeck, and N. Badler. Controlling individual agents in high-density crowd simulation. *Proceedings of the 2007 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, pages 99–108, 2007.

[13] Mehdi Moussaïd, Dirk Helbing, and Guy Theraulaz. How simple rules determine pedestrian behavior and crowd disasters. *Proceedings of the National Academy of Sciences*, 108(17):6884–6888, 2011.

[14] Fernando Alonso-Marroquín, Jonathan Busch, Coraline Chiew, Celia Lozano, and Álvaro Ramírez-Gómez. Simulation of counterflow pedestrian dynamics using spheropolygons. *Phys. Rev. E*, 90:063305, Dec 2014.

[15] Arianna Bottinelli and Jesse L. Silverberg. How to: Using mode analysis to quantify, analyze, and interpret the mechanisms of high-density collective motion. *Frontiers in Applied Mathematics and Statistics*, 3:26, 2017.

[16] J. Song, F. Chen, Y. Zhu, N. Zhang, W. Liu, and K. Du. Experiment calibrated simulation modeling of crowding forces in high density crowd. *IEEE Access*, 7:100162–100173, 2019.

[17] Bachar Kabalan. *Crowd dynamics : modeling pedestrian movement and associated generated forces*. Theses, Université Paris-Est, January 2016.

[18] A. Jebrane, P. Argoul, A. Hakim, and M. El Rhabi. Estimating contact forces and pressure in a dense crowd: Microscopic and macroscopic models. *Applied Mathematical Modelling*, 74:409 – 421, 2019.

[19] Litao Wang and Shifei Shen. A pedestrian dynamics model based on heuristics considering contact force information and static friction. *Transportmetrica B: Transport Dynamics*, 7(1):1117–1129, 2019.

[20] I.M. Sticco, G.A. Frank, F.E. Cornes, and C.O. Dorso. A re-examination of the role of friction in the original social force model. *Safety Science*, 121:42 – 53, 2020.

[21] Yaouen Fily, Silke Henkes, and M. Cristina Marchetti. Freezing and phase separation of self-propelled disks. *Soft Matter*, 10:2132–2140, 2014.

[22] Milad Haghani, Majid Sarvi, and Zahra Shahhoseini. When push does not come to shove: Revisiting faster is slower in collective egress of human crowds. *Transportation Research Part A: Policy and Practice*, 122:51 – 69, 2019.

[23] Dirk Helbing, Anders Johansson, and Habib Zein Al-Abideen. Dynamics of crowd disasters: An empirical study. *Phys. Rev. E*, 75:046109, Apr 2007.

[24] Rainald Lohner, Britto Muhamad, Prabhu Dambalmath, and Eberhard Haug. Fundamental diagrams for specific very high density crowds. *Collective Dynamics*, 2, 2018.