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On the influence of columns in densely populated corridors

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Abstract

An experimental and computational campaign was undertaken to measure the influence of columns in densely populated corridors. undertaken. A instrumented corridor of 5x12.54 m with two columns was enclosed by walls, and several hundred people were asked to walk repeatedly through the enclosed region. The maximum density achieved was of the order of 6 people/sqm, higher than what is deemed safe for many operating standards. The experiments were run with and without columns to see their influence. Remarkably, even at high densities, the columns had no noticeable influence on the pedestrian motion. Furthermore, the forces measured on the columns were very small (noise-level).

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1. Introduction

Columns appear in many architectural settings. In most cases they are essential supporting members that transmit loads from upper floors or upper structures to the ground. There is an understandable tendency to avoid the introduction of any columns into corridors frequented by large numbers of people. After all, if the columns are too large or too many, the effective passage width and hence the maximum capacity are reduced. Furthermore, pedestrians may collide to columns, leading to injury or accidents. The situation may be tolerable for low density crowds, but the natural reaction of any civil engineer or architect would be to avoid columns if the density exceeds 1 p/sqm. The authors faced situation where densities could reach more than this limit in corridors that were 5 m wide with elliptical columns of size 0.355 x 0.5 m, separated by a distance of 6.27 m (see Fig. 1a). A first set of calculations with the pedestian simulation tool PEDFLOW Löhner (2010) revealed that pedestrians would go around the columns almost unhindered up to densities of 4 p/sqm. Not unexpectedly, there were serious doubts on these results. Therefore, an experiment was performed to see if this was indeed the case.

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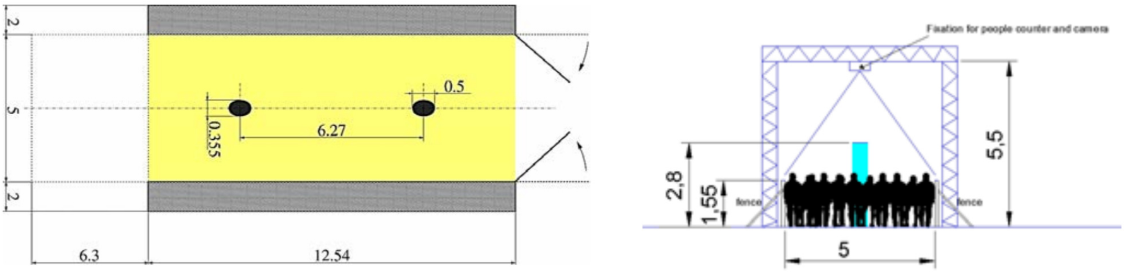

Fig. 1. Experimental setup: top and side view of corridor.

Fig. 2. View of experimental setup.

2. Test setup

The experiment consisted of a corridor 12.54 m long and 5 m wide, which was enclosed by walls and observation platforms (see Fig. 1 and Fig. 2). Two elliptical columns of size 0.355 x 0.5 m, separated by a distance of 6.27 m were placed in the middle of the corridor. Two swinging boards that acted as doors were mounted at the exit of the corridor in order to reduce the exit width and adjust the density. A series of cross beams above the corridor were used to attach both the cameras and pedestrian counters. The cameras were mounted above the pillars and the pedestrian counters at the entry and exit planes of the corridor. Fig. 2 shows the complete setup of the experiment. The measuring/filming equipment consisted of:

a) 2 high-resolution Canon 5D MK 3 cameras mounted at 5.5 m;
b) 6 high-resolution cameras (2 Canon 5D MK 2, 2 GoPro HD Hero, Canon G1 and Sony HDR-CX520) to document and make movies;
c) 4 floodlights (KinoFlo four bank with 5500K daylight light-tubes), mounted at 5.5 m;
d) A Panasonic BT-LH910GJ monitor;
e) 2 Laser-based PedCounters mounted at 5.5 m;
f) 6 LCM STA4 S type - 1500 kgs -rated load cells (3 on each pillar);
g) A Coolersystem for the PedCounters.

3. Group and path specification

The pedestrians were divided into the following sets of groups: individuals (33%), groups consisting of 5 individuals (33%), and groups consisting of 10 individuals (33%). The groups were given t-shirts of different colors (individuals: purple, groups of 5: orange, groups of 10: green) with the group number that allowed for a visual identification of members at close distance. In order to use the pedestrian tracking software PeTrackBoltes (2013) all participants were given white paper hats that had a black logo on its flat top. Participants were also told not to lower their heads too much while walking.

During the tests each participant/ group was asked to follow a predetermined path. A total of six paths were specified These were combinations of normal flow, cross flow and reverse flow (see Fig. 3). At any given time, 2/7th of the pedestrians were instructed to follow the figure of 8 (cross-flow) pattern. For half of the tests, 20 pedestrians were instructed to walk against the stream. During part of the test the pedestrians had to look towards a black board of wood and pause (0.5-1.0 seconds). This 'acknowledgement' behaviour was included in order to see what density buildup would occur in such a situation.

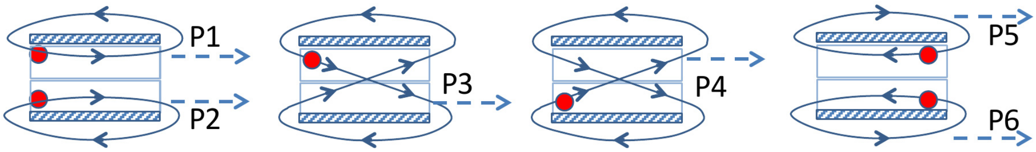

Fig. 3. Flow patterns specified (normal, cross, reverse).

Each test run was composed of 5 sequences: hot start, normal walk, acknowledgement, introduction of pedestrians walking against the stream (without acknowledgement). The target was to keep the pedestrians walking until a target density was reached and kept constant during at least 2 minutes. In order to simplify the lineup during the start of each test, the floor was marked with a diamond pattern that allowed pedestrians to find the desired start position and neighbour distance to achieve the desired density (see Fig. 4a and Fig. b).

Fig. 4. Flow plan and typical hotstart for low density cases.

For the so-called high density test the target density was set to 0.7 ped sqm/sqm (7 ped/sqm). In order to reach this density, 588 pedestrians were aligned in the so-called hot start position, one person per diamond as shown in Fig. 4 (left). For the so-called low density test the target density was set to 0.35 ped sqm/sqm (3.5 ped/sqm). In order to reach this density, 326 people were aligned in the hot start, one person per diamond in each row. A diamond row was left empty between two successive rows as shown in Fig. 4 (right).

Given the harsh climatic conditions (above 36 deg Celsius and very high relative humidity), the pedestrians were asked to walk for 15-25 minutes and then were sent to cooler rooms/buildings to rest and water.

Each test was run with and without pillars for comparison.

4. Tests performed

The timetables for the tests performed were as follows:
a) Low Density Test on the 3rd of July 2012
15:00 Registration and group assignment of pedestrians;
16:00 Set-up for a trial run;
16:15 Start of trial run;
16:25 End of trial run;
17:35 Start of the first run (low-density - with pillars - 4 sequences);
17:50 End of the first run;
18:00 Decision made to repeat the first run;
18:45 Start of the first run-second attempt (low-density - with pillar - 4 sequences);
18:59 Pedcounters failure due to high temperature;
18:59 End of the first run-second attempt;
19:10 Removal of pillars and preparation for second run;
19:48 Start of second run (low-density - without pillars - 4 sequences);
20:06 End of second run.
b) High Density Test on the 4th of July 2012
15:00 Registration and group assignment of pedestrians (group 1);
16:00 Registration and group assignment of pedestrians (group 2);
17:00 Set-up for first run;
17:30 Start of first run (high-density - with pillars - 4 sequences);
17:40 End of first run;
17:45 Removal of pillars and preparation for the second run;
18:25 Start of second run (high-density - without pillars - 4 sequences);
18:30 Power cut for the cameras and pedcounters (short circuit);
18:55 Problem fixed;
19:05 Start of second run - second attempt (high-density - without pillars - 4 sequences);
19:20 End of second run.

5. Video post-processing

Two HD video cameras (right/left) were used to record the pedestrians during the tests. The goal was to stitch the right and left images to form a single image covering the whole test area as shown in Fig. 5. Two difficulties appeared: lens distortion and discrepancy due to perspectives. Only the distortion could be partially removed. The perspective errors were not dealt with. All panorama movies were compressed into the suitable video format for PeTrack, the automatic pedestrian tracking software from JuelichBoltes (2013). Fig. 6 shows the automatic recognition and tracking of pedestrians via PeTrack.

6. Results and observations

6.1. Average density

Fig. 7 and Fig. 8 show the evolution of the average density for the cases run. The first observation is that the density for the low and high density cases is slightly **lower** for the cases with pillars - a counterintuitive result. Furthermore, the high density imposed at the start is not maintained - pedestrians tend towards densities of 3-4 p/sqm, which are close to the maximum possible flow rates seen in other experiments Predtetschenski and Milinski (1971). We remark that average densities only give an overall picture. Local densities recorded during the runs could vary between 2-8 p/sqm in space/time. Nevertheless, in order to obtain higher average densities, several attemps were made during the secod day to obstruct the exit of the corridor by closing partially the doors. This led to average densities that for a whilw approached 6 p/sqm.

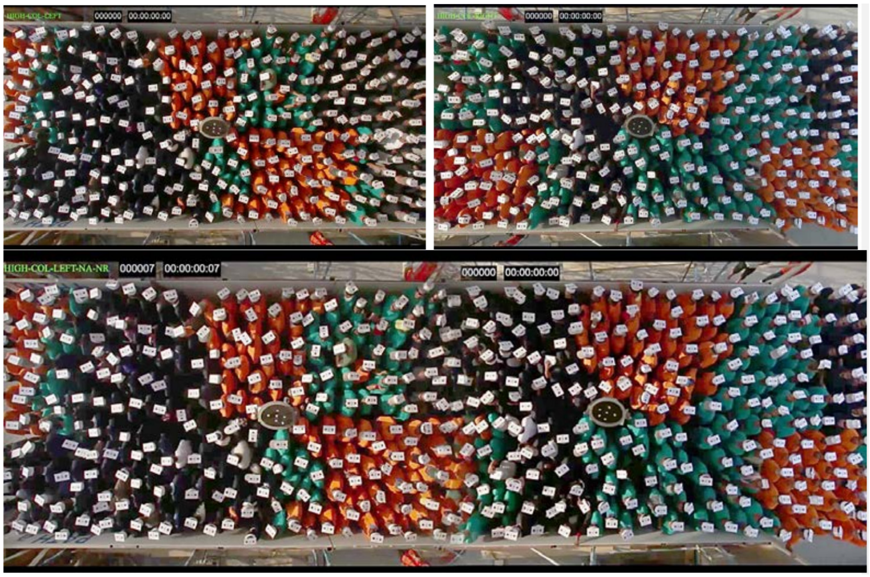

Fig. 5. Panorama of video cameras (start of high density case).

Fig. 6. Zoom with PedTrack registration.

6.2. Loads on pillars

Fig. 9a and Fig. 9b show the recorded loads on the pillars for the high density cases (the loads for the low density cases were negligible and are therefore not shown). Note that the forces measured are very low. If we consider any load of more than 10 kg as a pedestrian 'bumping' into a pillar, one can see that over a period of more than 12 minutes this occurred less than 20 times (!). This is very surprising, given the complexity of the (sometimes crossing) paths and the desire to stay together in groups. Furthermore, one can see that at the beginning, when the average density is highest, the lowest amount of 'bumps into pillars' occurs. This could be attributed to an increased attention of the pedestrians in high density situations, or a decreased attention due to exhaustion in the later stages of the test runs.

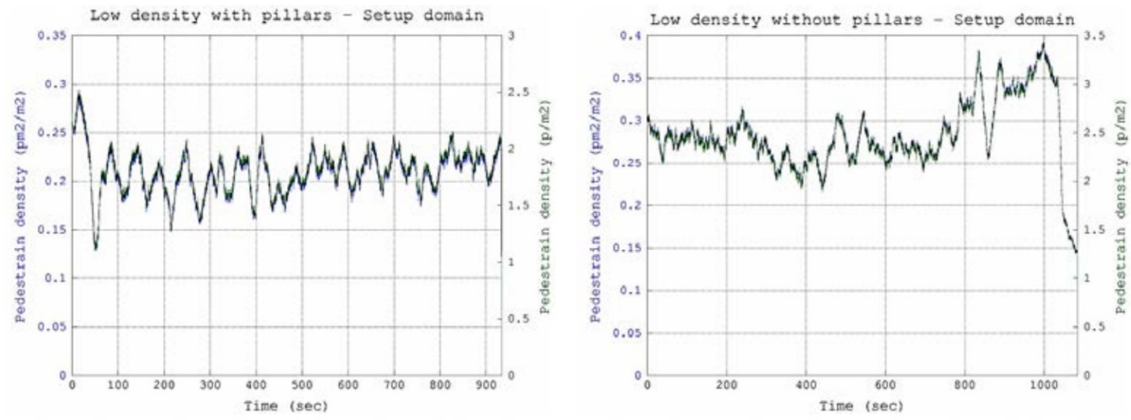

Fig. 7. Average density history for low density cases.

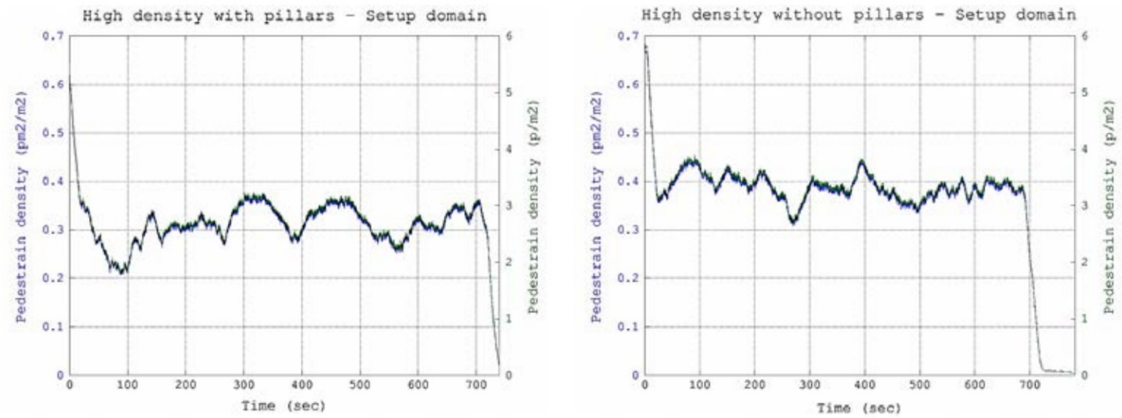

Fig. 8. Average density history for high density cases.

6.3. Lane formation

When the pedestrians could walk freely and were told not to cross from one side of the corridor to the other, the pillars acted as separators of two 'lanes'. Lanes could be seen especially in the low density cases where there is enough space and therefore no need to walk between the pillars.

6.4. Universal diagram

A first analysis of the density/velocity relationship (kindly provided by Dr. Jun Zhang from Juelich) for the recorded data is shown in Fig. 10. Note that the majority of the points lie in close proximity to the PM-curves (Predtetschenski and Milinski (1971)) recorded for pedestrians unaware of being monitored with a variety of everyday paths. In the case of the experiment performed here, pedestrians were aware of being monitored and we suspect that this added a certain discipline and desire to walk faster. Furthermore, the paths were very much predetermined and the group members followed their leader with the same velocity. We suspect that the 'outlier clouds' that would indicate a much higher thoughput/ capacity occur at the start, when density is very high and the room 'in front' is open (see also Fig. 7 and Fig. 8). This is being investigated more thoroughly at present.

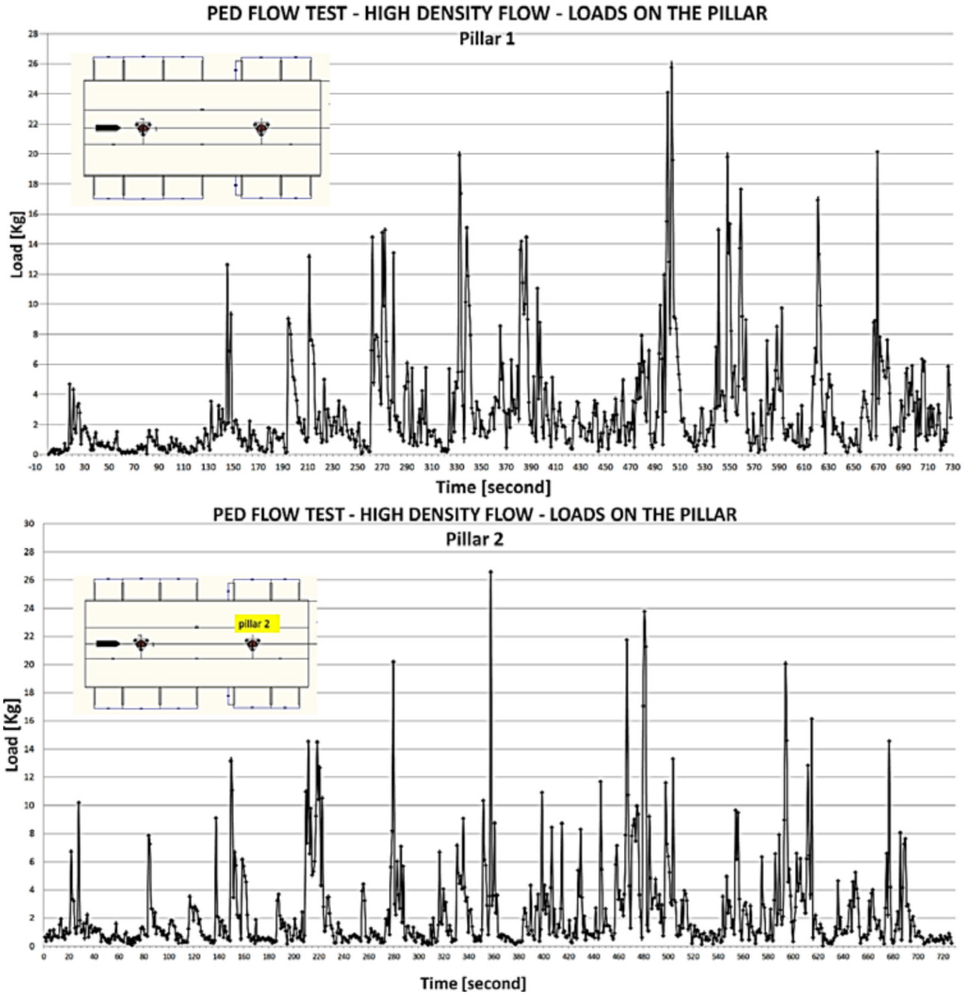

Fig. 9. Loads measured on the pillars (high density cases).

7. Conclusions

An experimental and computational campaign was undertaken to measure and understand the influence of columns in densely populated corridors. A corridor of 5x12.54 m was enclosed by walls, and up to 800 pedestrians, 33% individuals and 33% assigned to groups of 5 or 10 pedestrians respectively, were asked to walk repeatedly through the enclosed region in several path patterns. Two pillars with force measurement gauges were placed inside this corridor. An overhead laser measurement device was installed at the entrance to measure pedestrian fluxes, and cameras were installed above the columns to track the pedestrians. After an initial set of experiments showed no noticeable influence of flux rates and the forces of the columns were negligible, the density of the pedestrians was regulated by restricting the exit opening. The maximum density thus achieved was of the order of 6 people/sqm, higher than what is deemed safe for many operating standards. The experiments were run with and without columns to see their influence. Remarkably, even at high densities, the columns had no noticeable influence on the pedestrian motion. Furthermore, the forces measured on the columns were very small, particularly when the density of the pedestrians was highest.

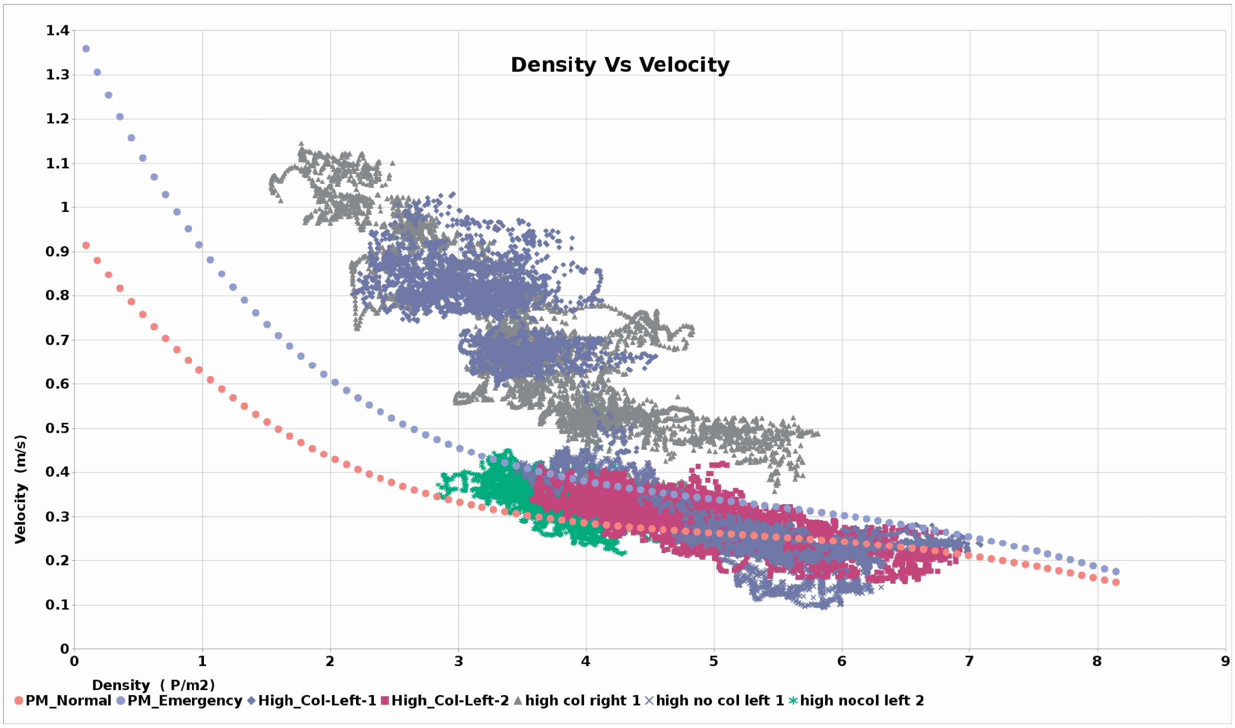

Fig. 10. Universal diagram.

Acknowledgements

It is a pleasure to acknowledge the large effort devoted by the staff of Premier Composite Technologies and its president Hannes Waimer in order to perform this experiment. Given the harsh climatic conditions laser measuring devices failed, shortcircuits appeared, cooling devices had to be invented. Given the low densities measured on the first day, more people had to be brought in. Whatever the problem, the staff of Premium Composites always found a quick solution to these problems, enabling a timely and successful completion of the experimental campaign.

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