Emergency Evacuation during a Disaster,
Study Case: "Timche Muzaffariyye –Tabriz Bazaar"

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SUMMARY:
Emergency evacuation during a disaster is a primary consideration of any confined space. There are many risk factors which can cause casualties such as earthquake, fire, terrorism, etc. Here we did emergency evacuation simulations for Timche Muzaffariyye of Tabriz Historical Bazaar Complex. Tabriz Historical Bazaar Complex has been recently registered as World Heritage site by UNESCO. Timche Muzaffariyye is an important part of Tabriz Bazaar and one of the most important carpet markets of Iran. Every year, at certain times cultural festivals are held at Timche Muzaffariyye and we observed emergency evacuation for those times by using simulation. Simulations were done by using distinct element method (DEM). DEM is a numerical method which can calculate position of each element (person) by solving equation of motion step by step. Different cases, with different number of people were considered. Results including evacuation time and people density on exits are introduced and compared.

Keywords: Emergency evacuation, distinct element method, Tabriz Bazaar, people density

1. INTRODUCTION

Safety is a primary consideration in any building. There are many risk factors which can cause casualties such as earthquake, fire, flood, terrorism, etc. Structural collapses are the most important factors of casualties during a disaster. If a disaster occurs, people who are caught in areas encounter dangerous situations. A building not only should service in normal conditions, but also it should be able to service in emergency situations. One of the important considerations in an emergency situation is evacuation of people. This is of great importance when a large number of people are or gathered together in a confined space such as mosques, subway stations, shopping malls, etc. To predict the normal evacuation or emergency evacuation of a place, an effective way is to simulate evacuation behavior. There are limited simulation models using distinct element method (DEM) to simulate evacuation behavior and crowd dynamics.

Kiyono et al. (1996) considered circular DEM elements as human beings and investigated behavior of the crowd flow that evacuated from an enclosed space to outside through the passage or the steps. They found that the model they proposed was able to simulate evacuation during a disaster. Kiyono et al. (1998) used DEM to simulate evacuation behavior during a disaster. They used circular elements and proposed an algorithm in which elements can avoid collision and pass each other naturally. They determined DEM parameters such as spring constants and driving force for human body based on experiments and simulated evacuation behavior for the explosion accident occurred at the underground shopping center near shizuoka station in 1980. Kiyono et al. (2000) used the same method to simulate the evacuation of an underground mall in Kyoto. Kiyono and Mori (2004) used elliptic elements to simulate emergency evacuation behavior during a disaster and validated the technique by comparing the simulation results with a real pedestrian flow. Alighadr et al. (2011) did the evacuation simulation for the Mosque of Azarbaijan University of Tarbiat Moallem. They found that number of exits, exits' width, and door opening angle have great influence on emergency evacuation time. Alighadr et al. (2011) observed effect of exits' width and number of people on emergency evacuation time and density around exits for Seghatol Islam Mosque of Tabriz Bazaar.

Here as a study case, we simulated the evacuation behavior of the Timche Muzaffariyye of Tabriz Historical Bazaar Complex. Tabriz Historical Bazaar Complex has been recently registered as World Heritage site by UNESCO. Timche Muzaffariyye is an important part of Tabriz Bazaar and one of the most important carpet markets of Iran. Every year, at certain times cultural festivals are held there. Different cases are considered and evacuation behavior, evacuation time, and density on exits are estimated quantitatively. Some sample photos of the cultural festival are shown in Fig. 1.

Figure 1. Photos of the cultural festival held in Timche Muzaffariyye of Tabriz Bazaar

2. STUDY CASE

2.1. Considered Study case

Study case takes place in the Timche Muzaffariyye of Tabriz Historical Bazaar Complex. Plan of the Timche Muzaffariyye and the plan considered for its simulations are shown in Fig. 2 and Fig. 3, respectively.

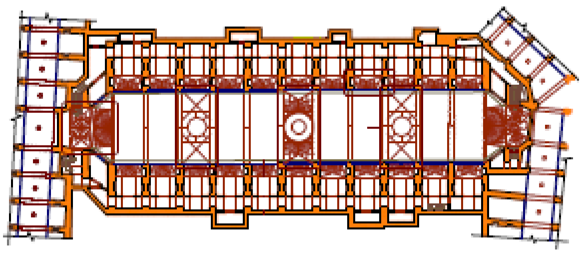

Figure 2. Plan of the Timche Muzaffariyye

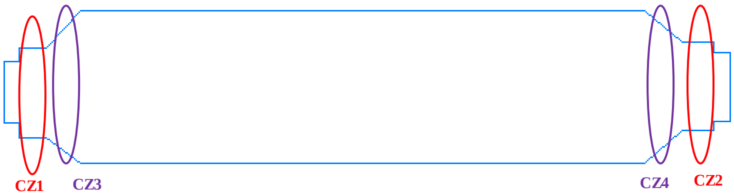

Figure 3. Plan considered for simulation of the Timche Muzaffariyye

2.2. Considered Cases for Simulation

According to photos taken from the Timche Muzaffariyye at different times of the festival, here we considered 4 different numbers of people i.e. 271, 547, 820, and 1080. In normal times and when there is less congestion of people, people are allowed to go out through either of the two exits but when the Timche is full of people, people are allowed to go out just through one exit so we considered evacuation from either one exit or two exits. So we considered 8 different cases which are illusterated in Table 1. Cases 1, 2, 3, and 4 are identical to cases 5, 6, 7, and 8, respectively but different in number of considered exits. Of course when going out from one exit is allowed, just people who are near the other exit are allowed to go out through it.

Table 1. Considered different cases

Case	Number of people	Number of considered exits
1	271	2
2	547	2
3	820	2
4	1080	2
5	271	1
6	547	1
7	820	1
8	1080	1

3. EVACUATION SIMULATION

3.1. Method

Distinct Element Method was used to simulate the emergency evacuation from a confined area. Human body is modeled as a circular element. Contact force acts on human body through virtual spring and virtual dashpot. In DEM, analysis can compute the position of each element (person) step by step by solving the equation of motion. The program simulates movement and decision making by means of adding the psychological forces to the physical forces. Algorithm that can consider avoidance, overtaking, and pass between elements naturally, is used.
The governing equations of motions are:

$$m_i \ddot{x}_i(i) = f_i^x(t) \tag{3.1}$$
$$m_i \ddot{y}_i(i) = f_i^y(t) \tag{3.2}$$

in which is mass of i-th element, f^x and f^y are various forces including driving force act on the element in x and y directions respectively.

Assuming that the acceleration is constant between small time intervals, Δt, the following equations can be obtained.

$$\dot{x}_i(t) = \dot{x}_i(t-1) + \ddot{x}_i(t-1)\Delta t \quad (3.3)$$
$$\dot{y}_i(t) = \dot{y}_i(t-1) + \ddot{y}_i(t-1)\Delta t \quad (3.4)$$
$$x_i(t) = x_i(t-1) + \dot{x}_i(t-1)\Delta t + \frac{1}{2}\ddot{x}_i(t-1)\Delta t^2 \quad (3.5)$$
$$y_i(t) = y_i(t-1) + \dot{y}_i(t-1)\Delta t + \frac{1}{2}\ddot{y}_i(t-1)\Delta t^2 \quad (3.6)$$

The position of each element can be calculated sequentially by solving above equations step by step. Psychologically people tend to keep a constant distance from others when they walk or run. In this study, this psychological distance is introduced as virtual radius. Independence of element spring, the virtual spring is also introduced. The contact judgment of two elements is determined by calculating the distance between the centers of two elements.

The parameters used for human body are based on experiments done by Professor Kiyono at Kyoto University. These parameters are illustrated in Table 2.

Table 2. DEM parameters for human body

Parameter	Value
Element spring constant (Normal)	1.07 x10^4 (N/m)
Element spring constant (Tangential)	5.35 x10^2 (N/m)
Element damping coefficient (Normal)	1.245 x10^3 (Nsec/m)
Element damping coefficient (Tangential)	2.79 x10^2 (Nsec/m)
Virtual spring constant (Normal)	6.62 x10^1 (N/m)
Virtual spring constant (Tangential)	3.31 x10^0 (N/m)
Virtual damping coefficient (Normal)	9.79 x10^1 (Nsec/m)
Virtual damping coefficient (Tangential)	2.19 x10^1 (Nsec/m)
Element radius	0.259 (m)
Virtual radius	0.72 (m)
Mass	3.62 x10^1 (kg)
Time interval	0.01 (sec)
Acceleration of driving force	0.837 (m/s^2)

3.2. Evacuation Analysis

We did the simulation for 8 considered cases. Snap shots of evacuation behavior for case 2 and 6 are shown in Fig. 4 and Fig. 5, respectively.

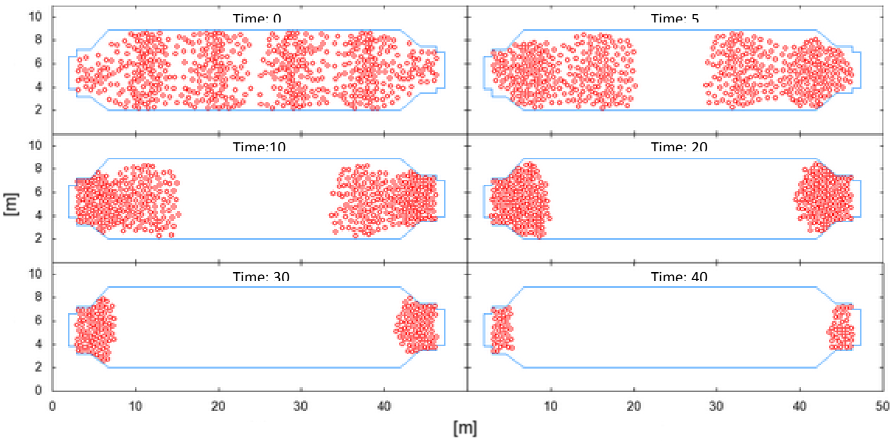

Figure 4. Snap shots of evacuation behaviour for case 2

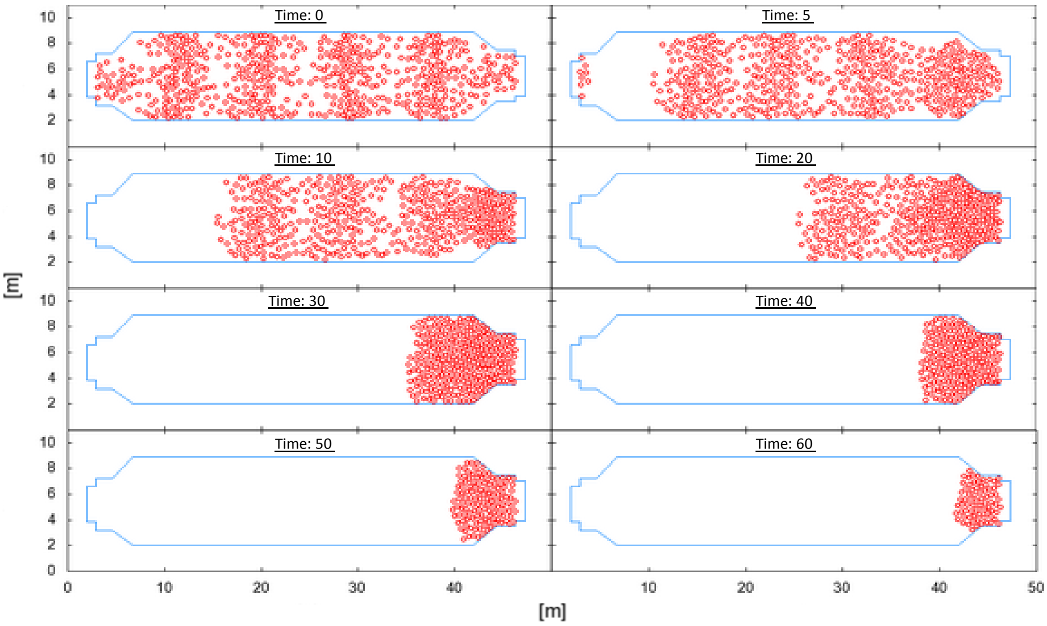

Figure 5. Snap shots of evacuation behaviour for case 6

Evacuation time is calculated to be 28, 49, 69, 89, 42, 76, 117, and 156 sec for cases 1 to 8, respectively which is illustrated in Fig. 6.

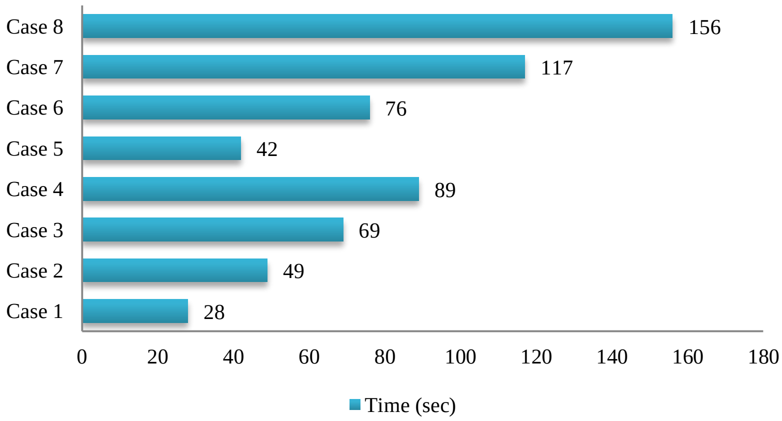

Figure 6. Evacuation time for different cases

As results show, in cases with evacuation from one exit when number of people are 2, 3, and 4 times, evacuation time increases 80%, 178%, and 271%, respectively and it increases 75%, 146%, and 218%, respectively when evacuation from two exits is considered. Increment of evacuation time for evacuation from one exit is 7%, 22%, and 24% more than for evacuation from two exits when number of people are 2, 3, and 4 times, respectively. So effect of number of people on evacuation time for evacuation from one exit is more than for evacuation from two exits.

To observe density on near exits, we considered 4 control zones. Control zone 1 and 2 are near exits and control zone 3 and 4 are near the part of reduction of width which are shown in Fig. 3. Time history of density in control zone 1 and 2 is shown in Fig. 7 and for control zone 3 and 4 is shown in Fig. 8 for eight considered cases.

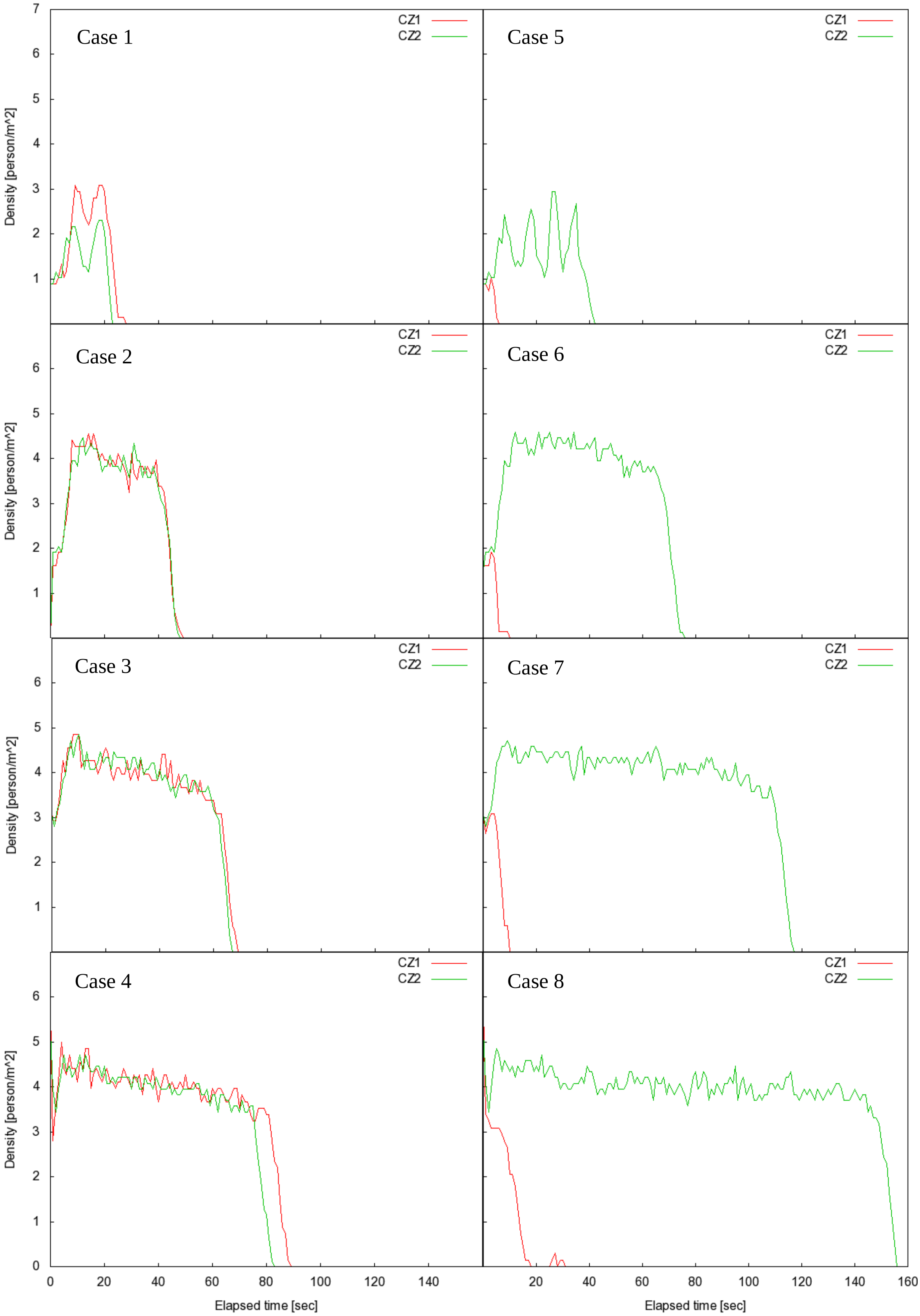

Figure 7. Time history of density in control zone 1 and 2 for different cases

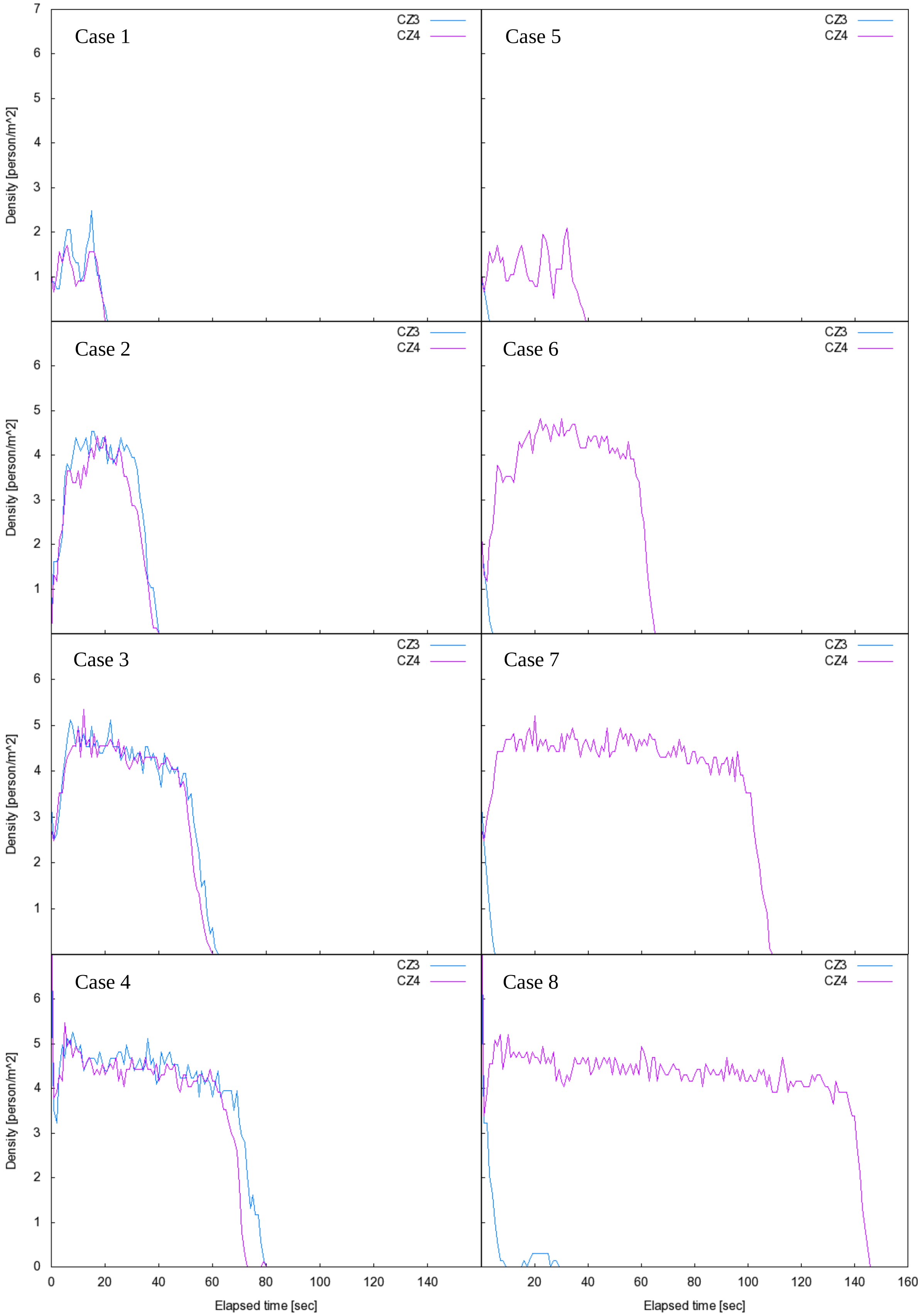

Figure 8. Time history of density in control zone 3 and 4 for different cases

Maximum densities in control zone 1, 2, 3, and 4 for 8 considered cases are illustrated in Table 3.

Table 2. Maximum density (person/m^2)

Case	Control Zone 1	Control Zone 2	Control Zone 3	Control Zone 4
1	3.08	2.29	2.48	1.69
2	4.56	4.46	4.38	4.43
3	4.85	4.72	5.12	5.34
4	5	4.72	5.27	5.47
5	1.02	2.93	0.88	2.08
6	1.91	4.59	2.04	4.82
7	3.08	4.72	3.22	5.21
8	3.38	4.84	3.21	5.21

As it can be seen, for cases 1, 2, and 5 (number of people less than or equal to 547) maximum densities in control zones 1 and 2 (near exits) are in average more than maximum densities in control zones 3 and 4 (near the part with reduction of width) but for cases 3, 4, 6, 7, and 8 they are in vice versa. It can be seen that case 6 (with number of people equal to 547 but with one exit number) plays intermediate role in increasing of maximum densities of control zones 1 and 2 comparing to those of control zones 3 and 4. It means that when number of people is going to be increased, maximum densities in control zones 3 and 4 are more than those in control zones 1 and 2, respectively, that might be arose from trapezoidal geometry zones of 3 and 4 comparing to the other two. And, it is evident that maximum densities in control zones 2 and 4 are more than those in the zones 1 and 3, respectively, when the case is with one exit number (cases 5 to 18).

4. CONCLUSION

One of the important considerations in an emergency situation is evacuation of people. This is of great importance when a large number of people are or gathered together in a confined space. One way to predict the evacuation behavior of people in a place is evacuation simulation. As a study case, we did emergency evacuation simulations of Timche Muzaffariyye of Tabriz Historical Bazaar Complex by using distinct element method (DEM).

Two series of simulations with two or one exit numbers were considered. In each series, we considered 4 different cases with different number of people 271, 547,820 and 1080, respectively. Evacuation times in cases 1 to 4 for series 1 (with 2 exit numbers) were 28, 49, 69 and 89 sec, respectively, and for series 2 (with 1 exit number) were 42, 76, 117 and 157 sec, respectively.

To observe density on near exits, we considered 4 control zones. Control zone 1 and 2 are near exits and control zone 3 and 4 are near the part of reduction of width. Maximum density is calculated to be 5.47 and 5.21 (person/m^2) for series 1 and 2, respectively.

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