



SIMULATION OF EMERGENCY EVACUATION BEHAVIOR DURING A DISASTER BY USE OF ELLIPTIC DISTINCT ELEMENTS

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SUMMARY

When people rush into an exit in a confined space under an emergency situation for an earthquake, a flood, or a fire, a huge force acts on a person and the force controls the movement of the people. In order to investigate such a dangerous situation, numerical simulation was done to grasp dynamic behavior of evacuees. Distinct Element Method (DEM) was used to simulate the emergency evacuation from the confined area. The evacuation behavior was analyzed by use of elliptic distinct elements. The movement of each element is determined by solving the equation of motion. We proposed a calculation algorithm in which element could avoid each other and turned naturally. In the past researches, human body was modeled as a circular element. A cross-sectional shape of the human body modeled is an important factor for the simulation especially in a high density state of a crowd. In this study, the simulation of the evacuation behavior was carried out by using elliptic elements. In order to represent various aspects of human behavior, we changed the strength of the spring, which virtually was generated when the element came in contact with others, according to the density of evacuees. The validity of the technique was checked by comparing the simulation results with a real pedestrian flow. Parameters under a super-high density state are also examined

INTRODUCTION

Accident occurred on a pedestrian bridge which connects a station and a fireworks site on July 21, 2001 at Akashi City, Hyogo. Eleven deaths and 100 or more injuries were caused by this accident. When people rush into an exit in a confined space under the emergency situation, a huge force acts on the people and the force governs their movement. In order to examine such dangerous situation, numerical simulation is the best way to grasp dynamic properties of a crowd behavior. The pedestrian movement model developed in this study can easily be applied to the issue of emergency evacuation.

In the past researches, a human body often is modeled as a circle element. In case of a high density state, however, ellipse element is more suitable. Therefore, the simulation of pedestrian movement using the ellipse elements was done in this research.

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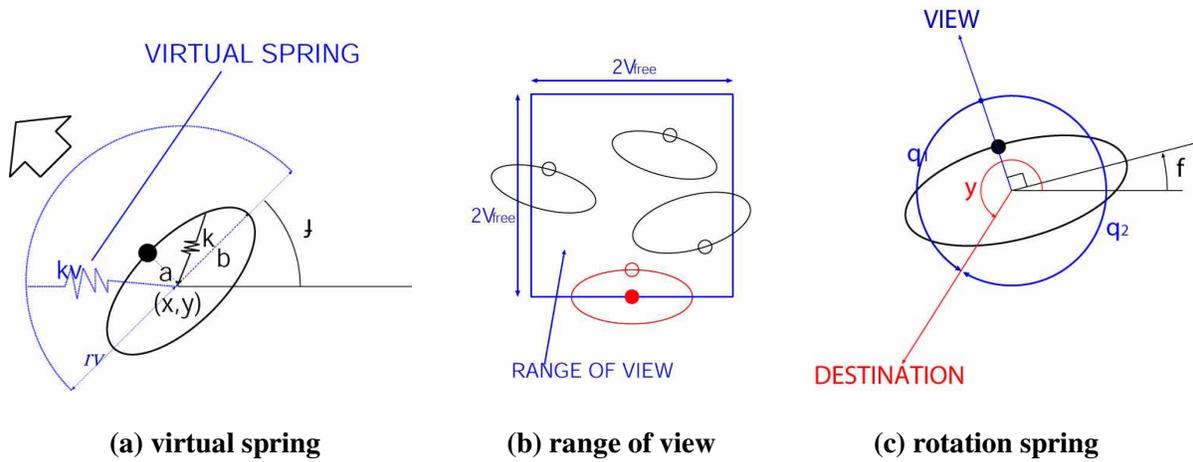


Fig.2 Human model by use of elliptic element

Table 1 Parameters of elliptic element

(a) population ratio, walking speed and sectional size

Classification		Ratio (%)	Speed (m/s)	radius (m)
under 15	male	2.0	1.02	0.16, 0.08
	female	6.5	1.09	0.14, 0.05
15-50	male	27.5	1.45	0.23, 0.11
	female	40.8	1.23	0.20, 0.11
50-70	male	5.0	1.19	0.23, 0.12
	female	5.8	1.04	0.20, 0.11
over 70	male	1.4	0.99	0.22, 0.12
	female	1.8	0.89	0.20, 0.11
Infant and mother		9.2	0.88	0.20, 0.11

(b) physical parameters of the element

Element spring constant (Normal)	1.26×10^4 (N/m)
Element spring constant (Tangential)	6.29×10^3 (N/m)
Element damping coefficient (Normal)	1.35×10^2 (Nsec/m)
Element damping coefficient (Tangential)	3.02×10^1 (Nsec/m)
Virtual spring constant (Normal)	3.38×10^2 (N/m)
Virtual spring constant (Tangential)	0.0 (N/m)
Virtual damping coefficient (Normal)	1.15×10^1 (Nsec/m)
Virtual damping coefficient (Tangential)	0.0 (Nsec/m)
Virtual radius	0.976 (m)
Mass	3.62×10^1 (kg)
Inertia moment	1.27 (kgm ²)
Walking acceleration	8.37×10^{-1} (m/sec ²)
Direction spring constant	2.69×10^1 (Nm/rad)
Direction damping coefficient	1.15×10^1 (Nmsec/rad)



(a) phase 1



(b) phase 2

Photo 1 Pedestrian flow in the shopping passageway



Fig.3 Rectangular zone

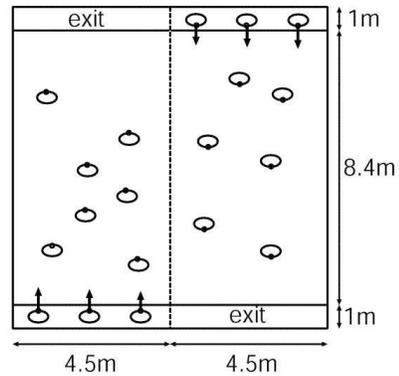


Fig.4 Analytical model

where the contacting point is defined at the mid point of P_1 and P_2 as shown in Fig.1 (b). The angle between P_1 and P_2 is expressed by the contact angle, ω .

Virtual spring

Psychologically people tend to keep a constant distance from others when they walk or run. In this study, this psychological distance is defined as a virtual radius. Independent of the element spring, the virtual spring is introduced as shown in Fig.2 (a). When an element approaches within the virtual radius of others, a rejection force acts on the element. As shown in Fig.2 (b), we introduced a square area as a range of view and the force of the virtual spring works inside of this area.

Direction spring

People keep his shoulder line perpendicular to the walking direction. In order to express this behavior, the direction spring was introduced around the center of ellipse element as shown in Fig.2 (c).

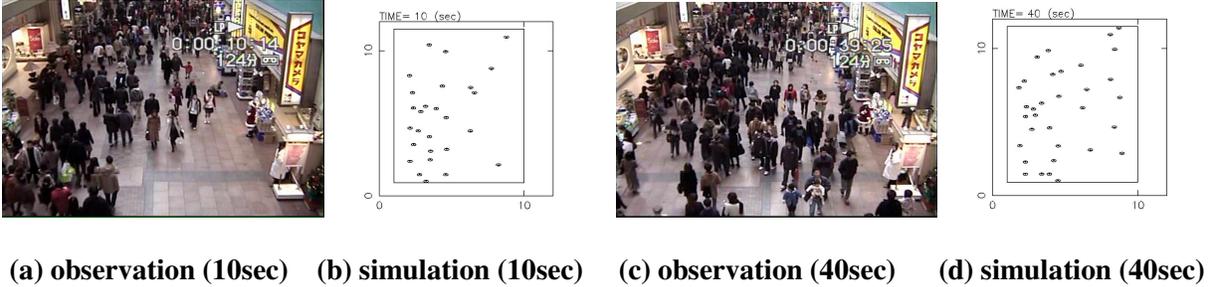


Fig.5 Comparison between observation and simulation for phase 1

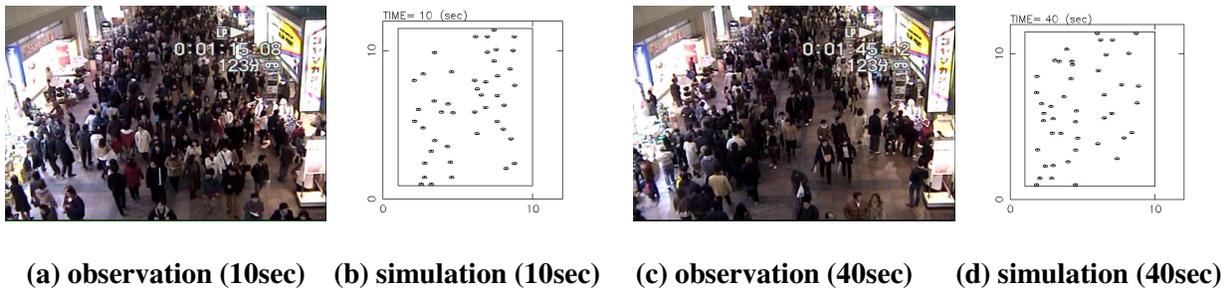


Fig.6 Comparison between observation and simulation for phase 2

Element parameters

Size and walking speed of the element is defined by using the observation results for pedestrian. It depends on the age and the sex as shown in Table 1 (a). Other parameters of the element are decided based on the simple experiment done by authors (Table 1 (b)).

COMPARISON WITH REAL PEDESTRIAN MOVEMENTS

Simulation results are compared with an actual pedestrian flow in the shopping passageway in order to examine how reproducibility this simulation technique has.

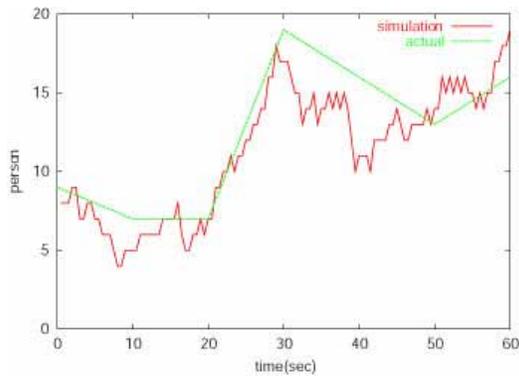
Outline

An example of the actual pedestrian flow is shown in a Photo 1. Pedestrian behaviors were recorded twice on videotape at the same point. They were named as phase1 and phase2, respectively, based on the difference of the density. The crowd was two way passing. As shown in Fig.3, the size of rectangular zone is 9.0m width and 8.4m depth. In order to compare the simulation with the observation, three parameters were investigated here; (1) amount of inflow, (2) initial density, and (3) walking speed.

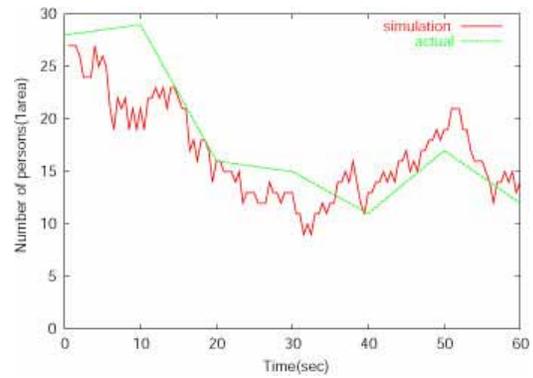
The analytical model of the simulation is shown in Fig.4. The target space was divided into two areas, and the area in which elements were generated was attached at the outside of the space. The parameter values obtained from the investigation were used as input data of the simulation.

Analytical results and examination of reproducibility

Comparison between the observation and the simulation for phase1 is shown in Fig.5, and phase2 in Fig.6. As the simulations are samples, they are not necessarily coincident with the observations. However, the



(a) phase 1



(b) phase 2

Fig.7 Comparison of the number of persons in the rectangular zone for phase1 and 2

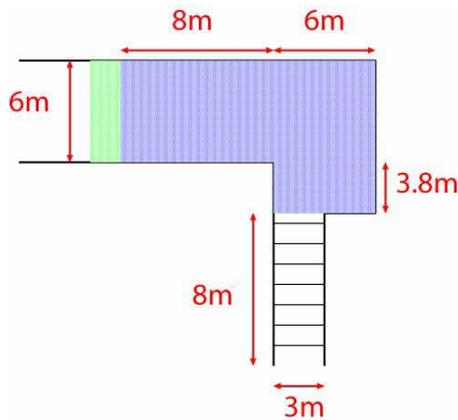


Fig.8 Analytical model

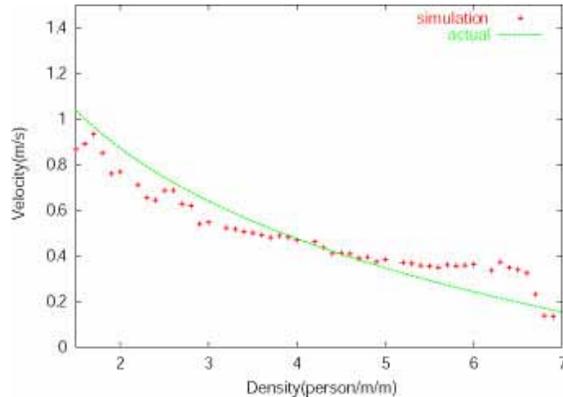


Fig.9 Density-speed relation

feature of the pedestrian movement for mutual passing can be simulated well. Fig.7 shows the comparison of the number of persons who exists in the rectangular area. The simulation result is in good agreement with the actual phenomena. Moreover, the contact of the elements when passing each other could not be seen in the analysis. This fact also agrees with the observation.

Consequently, if such parameters as initial density, amount of inflow and walking speed are selected appropriately, tendency of the pedestrian movement in the low-density state can be simulated correctly.

EXAMINATION OF THE VALIDITY IN A HIGH-DENSITY STATE

The pedestrian flow has property that walking speed decreases in accordance with an increase of the density. We propose a regression equation of the density-walking speed relation in a high-density state. By comparing the simulation results with the regression equation obtained by observation, the validity of the simulation model in a high-density state is examined.

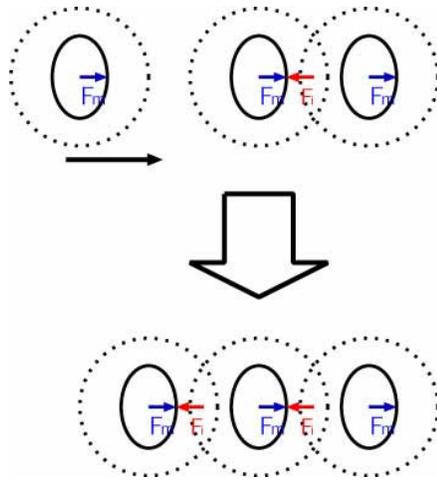


Fig.10 Virtual spring before improvement

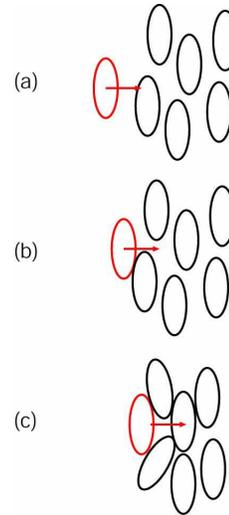


Fig.11 Super-high density state

Table 2 Maximum crowd density and force

Remove rate (%)	Maximum crowd density (person/m ²)	Maximum force (G)
0.0	9	0.94
0.2	10	1.19
0.4	13	2.41
0.6	15	3.46
0.8	17	4.67
1.0	17	5.02

The analytical model is shown in Fig.8. It is a part of a pedestrian bridge on which the accident occurred in 2001. According to the initial density of 3 (person/m²), the elements are arranged in the blue area in the figure. Three persons were generated as an inflow in every one second from a green area. The density-speed relation obtained from the analytical is shown as red symbols in Fig.9. On the other hand, the density-speed regression curve for a high-density state obtained by the observation can be written as

$$v = 1.32 \log_{10} \frac{9.16}{\rho} \quad (2)$$

where ρ is density (person/m²) and v walking speed. This relation is plotted as a green line in Fig.9. Both are in good agreement. Therefore it is found that the virtual spring works appropriately in the simulation. The average speed of the pedestrian movement decreases when the density increases.

PARAMETERS FOR SUPER-HIGH DENSITY STATE

In the low- and high-density states shown above, the situation in which accident occurs can not be expressed. As the virtual spring works even in a super-high density state, the element is difficult to contact each other and the elements keeps a fixed distance (Fig.10). In order to describe the super-high density

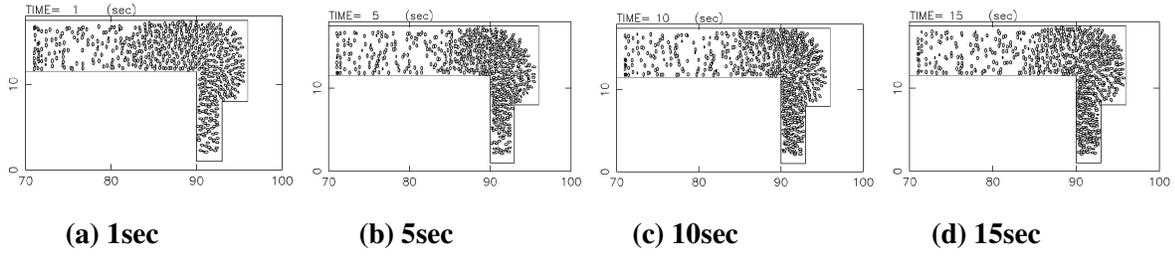


Fig.12 Simulation of pedestrian movement (remove rate: 0.0)

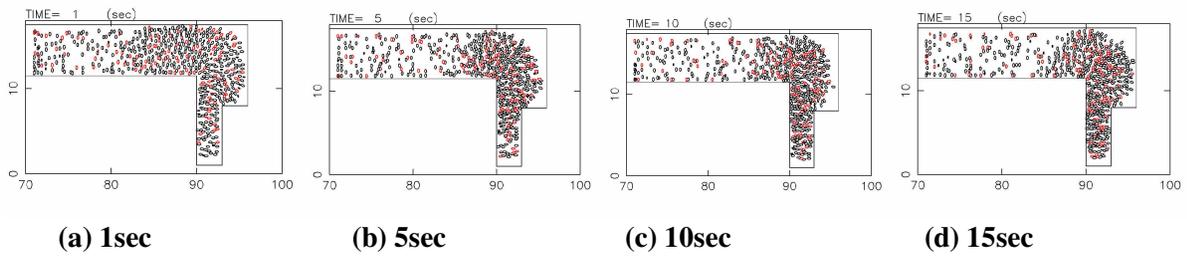


Fig.13 Simulation of pedestrian movement (remove rate: 0.2)

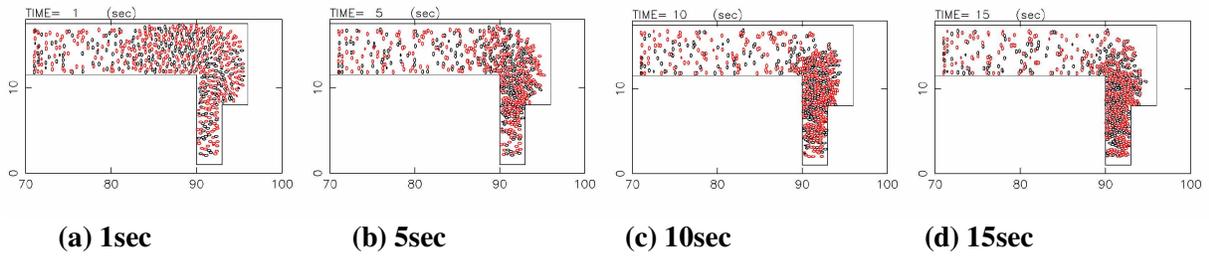


Fig.14 Simulation of pedestrian movement (remove rate: 0.6)

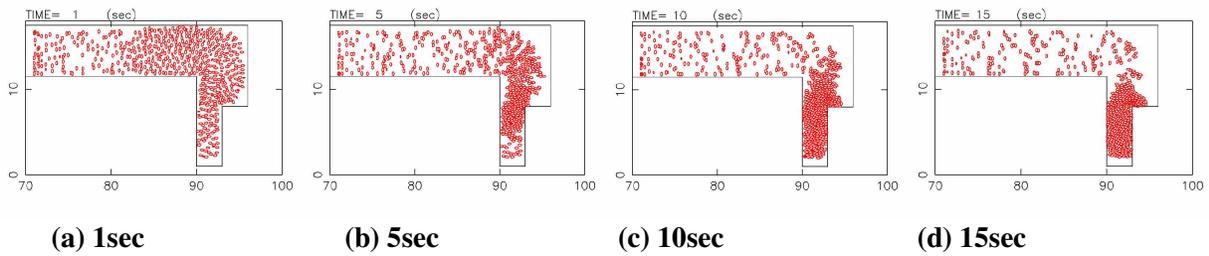


Fig.15 Simulation of pedestrian movement (remove rate: 1.0)

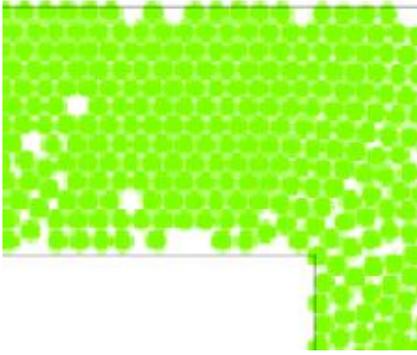


Fig. 16 Simulation by circular elements

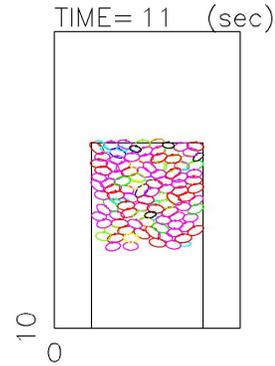


Fig.17 Simulation by elliptic elements

state, element parameters were improved in this study. We here removed the virtual spring. The element without the virtual spring walks forward by itself, because it does not receive forces from surrounding elements. This situation is shown in Fig.11.

Analysis is done by changing the rate of the persons whose virtual spring is removed (we call it 'remove rate'). The rate is varied from 0 to 1 with every 0.2. The model used here is the same as that of a high-density state. Initial density is set as 7 (person/m²) and the amount of inflow 10 (person/s). A part of the result is shown from Fig.12 to Fig.15. The maximum pedestrian density measured and the maximum force that acts on person are shown in Table 2. The density and force acts on person are increasing with the remove ratio. The super-high-density state is reproducible by changing the remove rate.

In actual, a person will be in a dangerous condition if three times larger force of his weight acts on. The ultimate value of the density is said to be 15 (persons/m²). If such facts are taken into consideration, the remove rate of 0.6 is an adequate value for describing the super-high density state.

COMPARISON WITH CIRCLAR MODEL

Fig.16 shows an example of the simulation by using circular elements. The elements arranged regularly and are not realistic. An example by using elliptic elements is shown in Fig.17. As shown in the figure, the elements are randomly arranged in the high-density state. In a real phenomenon, the arrangement of the element is more complicated when the density becomes high. The elliptic model is more realistic.

In the circular model, the maximum density was about 5 (person/m²) and the maximum force was about 4G. Circular model can not describe the high-density state beyond these values. This fact also can be found in Fig. 1.

In the elliptic model, the super-high-density state can be simulated as shown in Table 2, and the force also can be computed as an appropriate value.

CONCLUSIONS

In this study, the pedestrian movement simulation using elliptic elements was done and the validity of the simulation technique was examined. The main results of this study are;

- (1) Simulation technique for the pedestrian movement using elliptic elements was developed. The ellipse model could express realistic behavior of the pedestrian movement.
- (2) This simulation can reproduce the tendency of a pedestrian movement in low-density state if such parameters as initial density and the amount of inflow are adopted appropriately.
- (3) The technique developed provides appropriate values of the force acting on the element, pedestrian density, and walking speed in a high density state.
- (4) The super-high density state can be reproducible by changing the rate of the person whose virtual spring is removed.
- (5) This technique can describe more realistic element arrangement, force and density than the circular model.

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