An Experimental Study on the Evacuation Flow of Crowd Including Wheelchair Users

Taku Shimada[1] and Hideo Naoi[2]
[1]*Dept. of Architecture, Faculty of engineering, Tokyo Univ. of Science /Akeno Fire Research Institute*
[2]*Dept of Architecture, Faculty of engineering, Tokyo Univ. of Science*

ABSTRACT

Until now, the evacuation of wheelchair users from buildings in an emergency condition, cf. a fire, has not been considered enough.

In this study, we made five experiments to grasp the characteristics of crowd evacuation flow including wheelchair users. Then we intended to grasp the relative decreasing trend of a flow coefficient to the able-bodied people group. Through these experiments, we recognized as follows:

1. In the range that crowd density is 2-8 [people/m^2] the flow coefficient increases as the density increases.
2. The flow coefficient decreases as the wheelchair users mixing rate in the crowd increases, but inclination of decrease becomes gradual.
3. The width of door has little effect on the flow coefficient.
4. The flow of a self-moving type wheelchair is smoother than the assisted moving type.

As a result of this study, we proposed a calculating formula using ergonomics factors, personal occupation area, crowd speed and the wheelchair users mixing rate, which shows nearly the same downward tendency as our experiments indicated.

Keywords: Wheelchair, Crowd, Flow coefficient, Evacuation

1. INTRODUCTION

After the "Heart Building Law" was enacted, the number of buildings easily accessible for wheelchair users have increased. However, this transition is concerning only the normal access to a building. The evacuation of wheelchair users from buildings in an emergency condition, cf. a fire, has not been considered adequately until now.

When evacuation flow is calculated, 1.5[people/m/s] is used as the flow coefficient when the crowd passes the door etc. now. This value is adopted in the evacuation safety verification method of the Building Standard Law.

The flows at entrance are almost 1.0-2.0[people/m/s] according to Togawa's observation [1], and the crowd flow coefficient at evacuation is 1.5[people/m/s] which is assumed to be suitable. Moreover, according to Okada [2], the crowd flow coefficient that has the speed as fast as the committing crowd when the crowd density is 1.0-4.0[people/m^2] constantly indicates 1.5 [people/m/s] at the horizontal passage. The flow in the gateway is flow granulates matter rather than that of fluid, because gateway

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is narrower than the passage in general. It may be considered that 1.0[people/u/s] by using 55-60[cm] as width (u) of the unit because the relation between width and the amount of flow is not directly proportional in general.

However, the crowd mentioned above is a group including only able-bodied people and physically disabled people, etc. are not included. An evacuation plan in a general building should be considered under conditions including wheelchair users when thinking about the grows of the elderly society and physically disabled people's participation. The findings concerning the decreases level of the amount of flow according to such crowds in compare with the able-bodied people have not been obtained yet. To obtain basic material to investigate the flow coefficient of the crowd including the wheelchair users, the experiment that reproduced this situation was done, and analyzed.

2. EXPERIMENTAL METHODS

2.1 Condition

In this study, we made five experiments to grasp the characteristics of crowd evacuation flow including wheelchair users. Of course, it's impossible to accurately reappear the evacuation situation in case of an actual fire, so as the plan of this experiment, we made modeled situation of the evacuation flow by some instructions, and tried to comprehend the relationship between physical factors. Then we intended to grasp the relative decreasing trend of a flow coefficient in comparison with the able-bodied people group. The following conditions are set in this policy.

Condition of the experiment

- A crowd density of 2 to 8 [people/m^2].
- An entrance width of 750 to 2,400 [mm].
- A wheelchair users mixing rate of 0 to 100[%].
- Wheelchair type (self-moving type, assisted moving type)
- Existence of detention space (room type, corridor type).

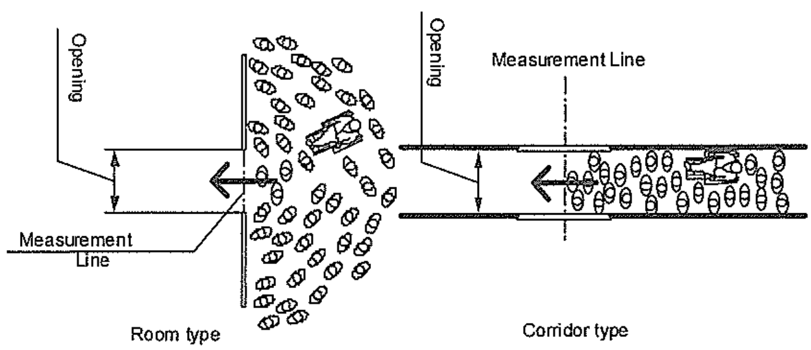

Figure1 Detention space type

2.2 *Experimental setup*

The reproduced evacuation space of the temporary housing as shown in *Figure 2* was set up in a gym. The finish of the floor is wooden flooring. The wall is made of plywood panels, and set of the entrance. The panels were built temporarily and each panel was supported and fixed by person. During the experiments, the crowd pushed panels, but the inclination was only about several cm, and it does not large affect the results. Enough space around the panels was set for the crowd to act freely.

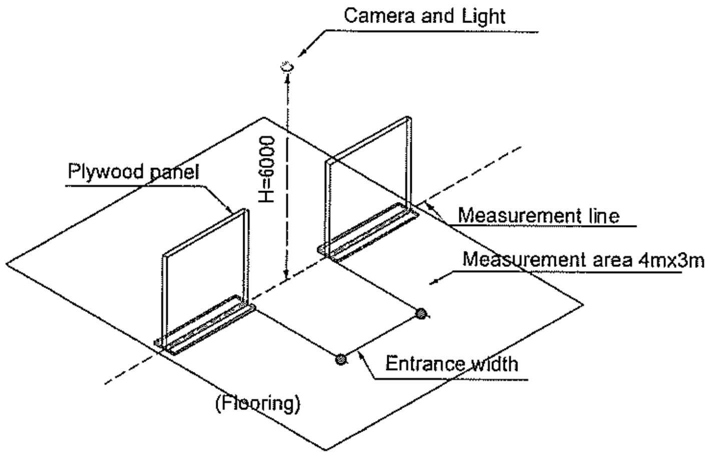

Figure 2 Experimental setup

2.3 *The examinees*

The examinees were 40-88 able-bodied students. The examinees wore casual wear without any coats, etc. Examinee wore only socks because of the constraints of the experiment location. Examinee carried no luggage. The examinees of the wheelchair users are able-bodied students. These trial crowds were judged to have no problem by referring purpose of this study. The wheelchairs used in this experiment were JIS (Japanese Industrial Standard) large type which can be generally rented. Realistically, it is possible to use a small wheelchair. However, it was difficult to consider that it had a major influence on the experiment's results, and also because it was a safety side, judged that there was no obstacle.

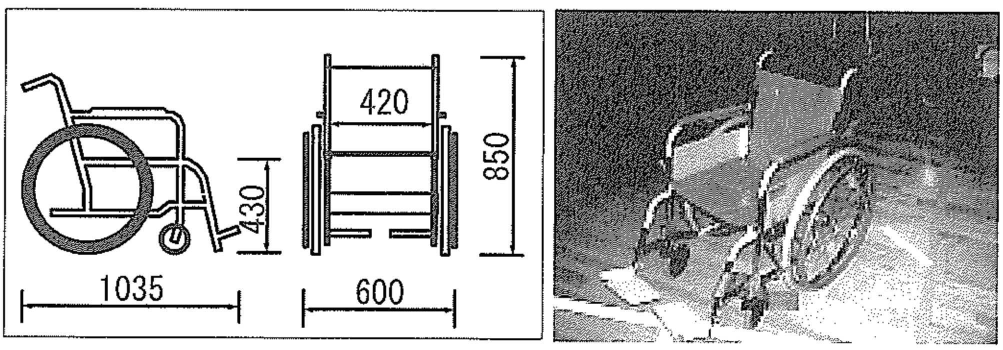

Figure 3 Wheelchair

2.4 Operation

The measurement line was set at the center of the entrance. A camera and lighting were set up with 6.0 [m] just above the line. We captured the reflected light from the reflection seal attached on each examinee's parietal side. We measured the lights passing on the measurement line every 1/10 second. The examinees were distributed evenly in a semicircle around the entrance. In addition, the examinee's interval was adjusted to the crowd density depending on the existence of the examinee's body contact. Each examinee passed the entrance was not given any physics handling and only had a common image of the crowd density and passed the entrance. 3-5 trials were done at each condition.

2.5 Analysis methods

The image taken by the camera was converted into position coordinate data using the motion analysis machine, and basic data such as transit time were obtained. 5 people of first and the last low of the crowd were excluded from the data. Because they were not effected by the crowd.

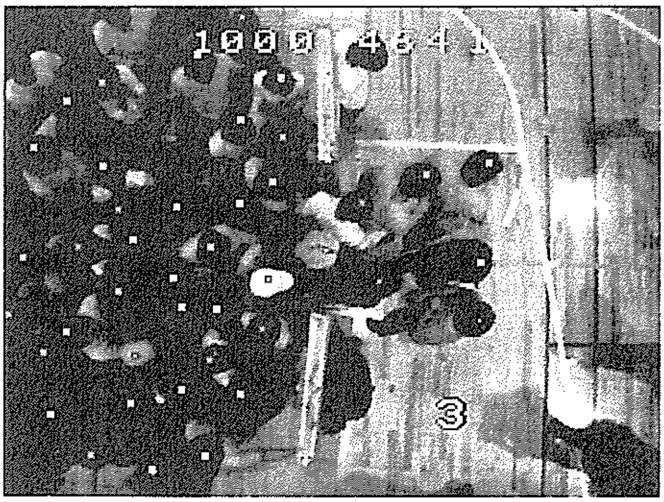

Figure 4 The image of camera

3. RESULTS AND CONSIDERATIONS

3.1 Observation result of the crowd flow

3.1.1 The stability of crowd flow

To confirm whether steady crowd flow was reproduced in two room settings, one example of the crowd density transition by the elapsed time was shown in *Figure 5* and 6 respectively. The data was obtained only for able-bodied people of the range 1.0[m] behind the measurement line and the entrance width. The plotted points were averaged by every 5 scene measured every 1/10 second. Some differences are observed. Because the number of examinees within the narrow range is small, and the influence was given to the numerical value of examinee. Moreover, there are some trials from which certain decreases in the density are seen on the room space type of *Figure 5*. One of the causes is considered to be the decrease of the pressure from the back according to decreasing the number of staying people with the passage of time. It can be judged that a remarkable change in the density is not seen, and roughly steady stationary flow is reproduced.

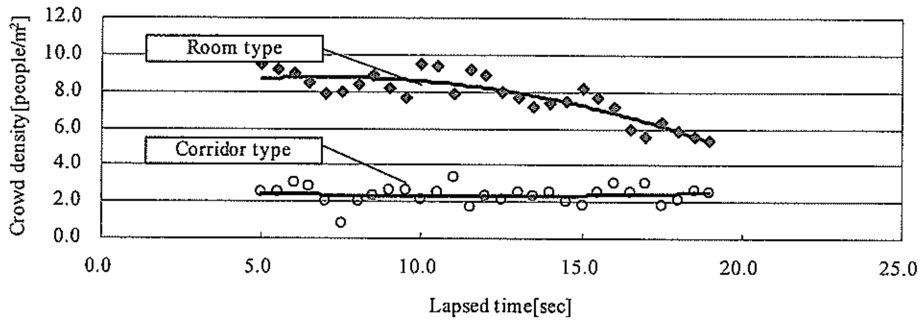

Figure 5 Transition of crowd density (Detention space type)

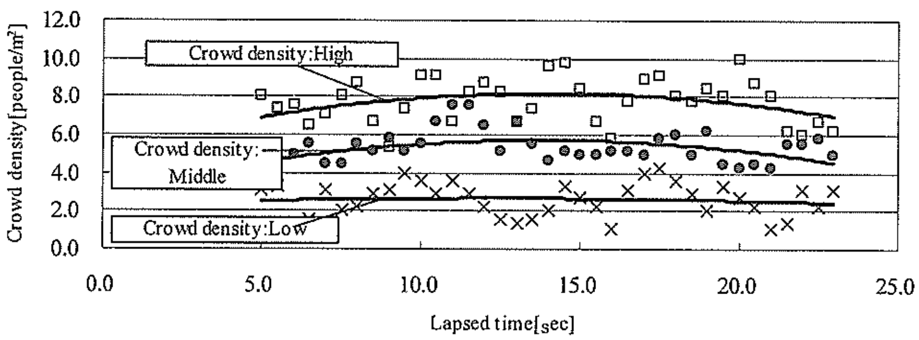

Figure 6 Transition of crowd density (Density level)

3.1.2 The able-bodied people and the wheelchair user's movement tracks

Figure 7 shows one example of tracks for 15 of able-bodied people and 3 wheelchair users extracted at random with a room space type and entrance width 900[mm]. People passed the entrance, almost similar tracks are drawn, and they show like a sector shape. From a detailed observation, the able-bodied people's track shows side movement and meandering. It should be considered that the influence from which the movement of the neck and the neck such as shakes is reflected in tracks. However, it is thought that the influence is comparatively little as appear in tracks after the entrance. The biggest factor is that people don't travel in a straight line while entering space forward in the crowd. It is said that the able-bodied people will be urged to travel ahead with side movements. On the other hand, the wheelchair users travel almost in a straight line. This is thought to be the one by the difference of the movement form. It can be judged that both the wheelchair users and the able-bodied people do not indicate unnatural movement, and the crowd traveling movement with a general stay is reproduced according to these tracks and observation.

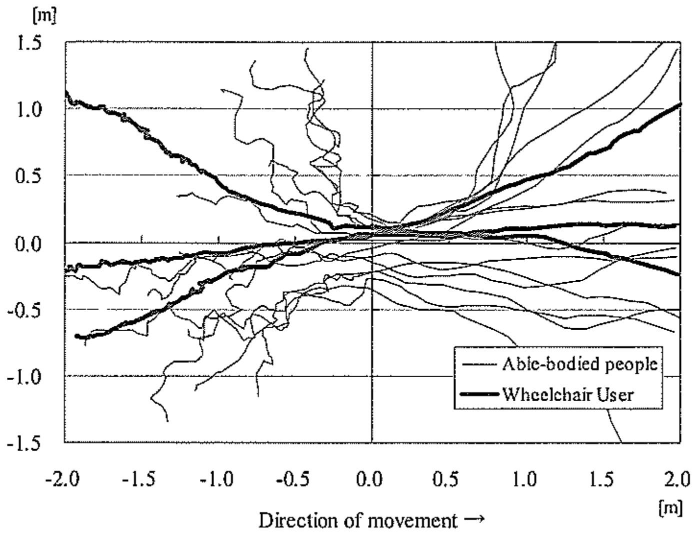

Figure 7 Example of tracks

3.2 Various conditions that influence the flow coefficient

3.2.1 Comparison of stay space types

The flow coefficient of the wheelchair users mixing rate according to each setting condition is shown in *Figure 8* for the retention space and *Figure 9* for the crowd density. In *Figure 9*, the flow coefficient of the room space with the stay becoming higher than that of the coefficient of the corridor space type without the stay. The crowd density is thought to be the cause. Because the crowd density rose by the stay and the amount of flow increased, though the condition except the stay space type is similar, the flow coefficient reached a big value.

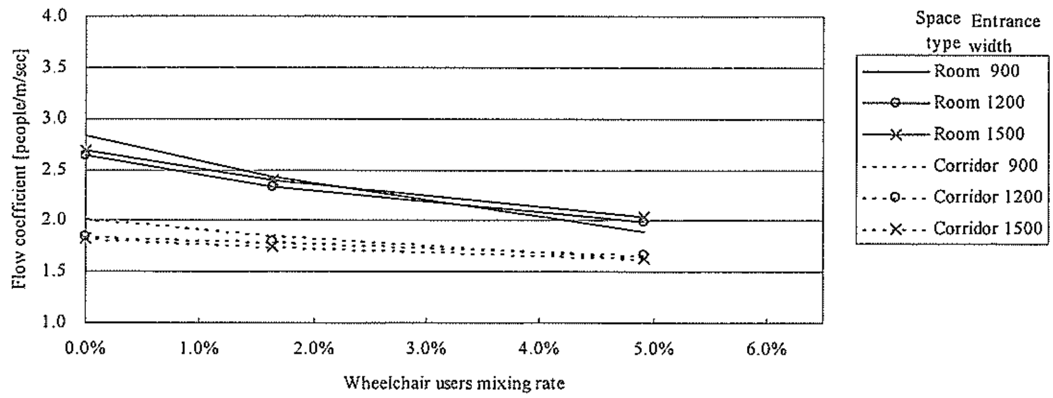

Figure 8 The flow coefficient to a wheelchair users mixing rate (Detention space type)

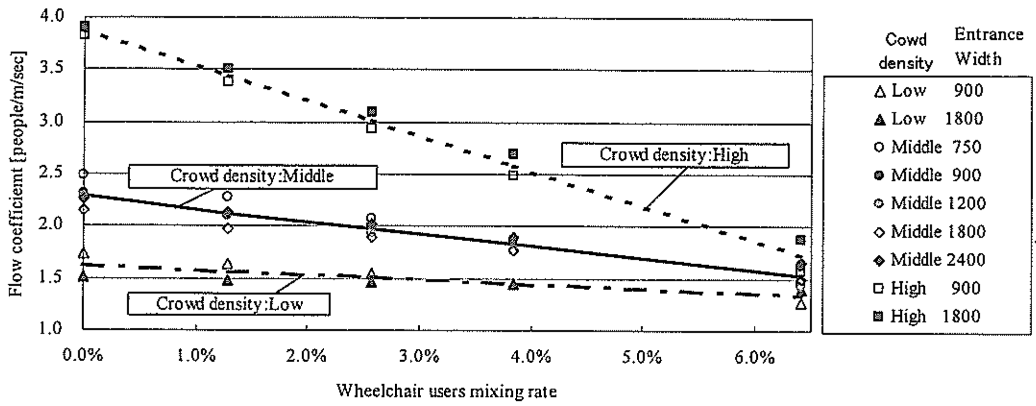

Figure 9 The flow coefficient to a wheelchair users mixing rate (Density level)

3.2.2 Influence of wheelchair users mixing rate

As it is a natural result that *Figure 8 and 9* shown the flow coefficient decrease according to the mixing rate increase. The decrease of the flow coefficient is said to be straight to an increase of the wheelchair users mixing rate and to be proportional to it.

A tendency can be found that the inclination of the decrease rate of the flow coefficient as the crowd density becomes higher. By these results, it is expected that the flow coefficient decrease in most straight lines at a high mixing rate. But further research is necessary to find how the decrease in the straight line is adopted.

3.2.3 Influence of an entrance width

An almost similar value and the tendency are indicated according to *Figure 8 and 9* though there are some differences even if the entrance width is different. The level of the influence is smaller than that of other conditions. Hereafter, observed details are described. In small entrance width (750[mm], 900[mm]), people are observed to pass through the entrance and twisting their body. Moreover, people's flow doesn't become interrupted though a surrounding able-bodied person enters in front of the wheelchair user in 0.5-1.0[m] before the entrance when the wheelchair users passes, and the amount of flow decreases.

However, when a part of the wheelchair approached the entrance, people were observed to stop at the rear and both side of the wheelchair, and the flow was divided into parts.

When the entrance width increases more than 1,200[mm], the wheelchair users and the able-bodied people smoothly passed at the same time. It can be said that the entrance width between 900[mm] to 1,200[mm] will disturb the simultaneous passing because the simultaneous passing was not observed when the width was 900[mm].

3.2.4 Influence of the crowd density

Actual crowd densities were low (2-3[people/m^2]), middle (3-5[people/m^2]) and high (5-8[people/m^2]) in comparison with set crowd densities.

In *Figure 10,* the flow coefficient reaches high by the higher crowd density. The influence of the wheelchair is large, and the decrease of the flow coefficient is also larger when the crowd density becomes higher. Various conditions like pressure from the surroundings etc. are thought as causes. However, these experiment results could not explain clearly about these conditions.

In *Figure 10,* the crowd density of each trial is averaged, and the flow coefficient to the crowd density was plotted according to the wheelchair users mixing rate. From *Figure 10,* the difference is somewhat seen in the flow coefficient in the crowd density of 5[people/m^2] or more. However, the difference doesn't depend on the wheelchair users mixing rate overall, a similar tendency is shown, and the flow coefficient is proportional to the crowd density. It is because there were a lot of trials at medium crowd density that the plotted points have concentrated on 3-5[people/m^2]. *Figure 10* showed linear regression line.

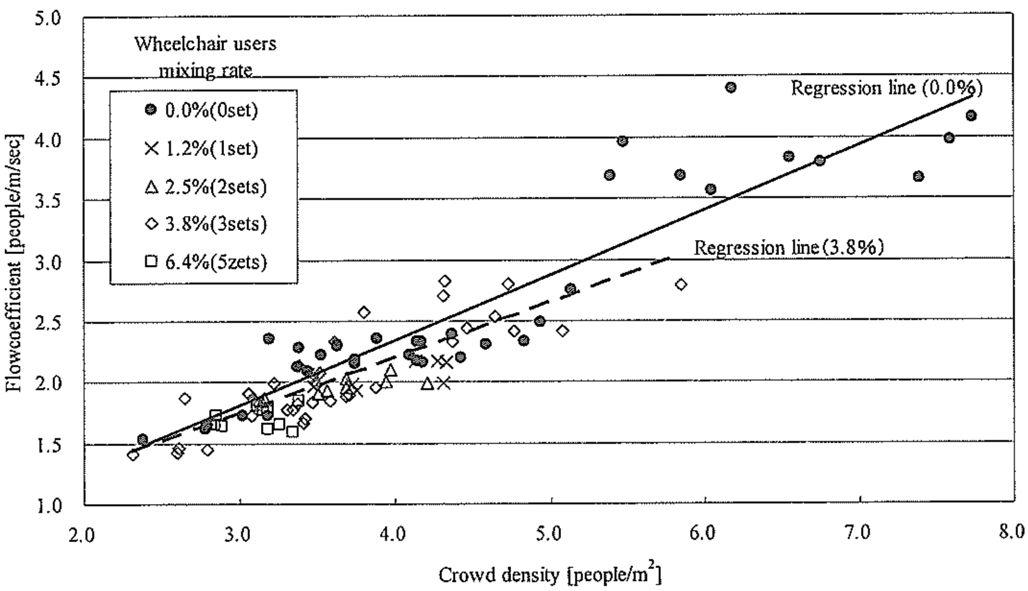

Figure 10 The flow coefficient to crowd density

In comparing the flow coefficient at the wheelchair users mixing rate 0.0[%] in *Figure 9* with that of research [3], difference is recognized at the high crowd density, but not at the low crowd density (2-4[people/m^2]). It is regarded that the results from experimental crowds are different from that of an actual observed crowd. The examinees are freer in their individual movement than real commuting people accompanied with luggage such as bags etc. Moreover, measuring area of the crowd density is the entrance width x 1.0[m] behind the measurement line.

Therefore, the problem in the difference of the crowd density was large remained in the measurement of it. Especially, this tendency was strongly seen in a high crowd density. So it is necessary to improve the measurement method. Then, the occupation area was drawn by the Boronoi division that made the examinee as a basic point. This becomes the reciprocal of the density. *Figure 11* shows the drawing example.

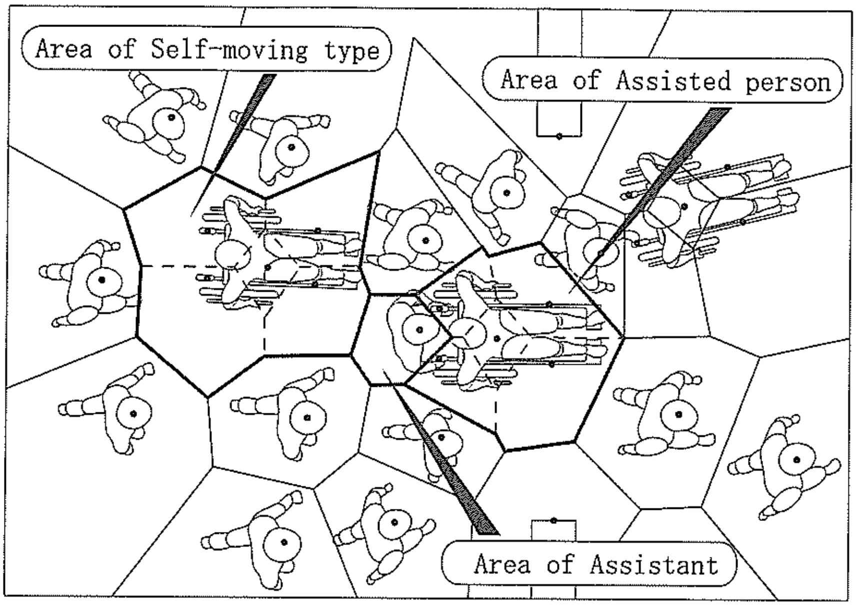

Figure 11 *Occupation area*

Boronoi diagram partitioned to allocate an area that is nearer than any other area when some points were shown on a plane. *Figure 12* shows the relation between the distance and the measurement line and the occupation area.

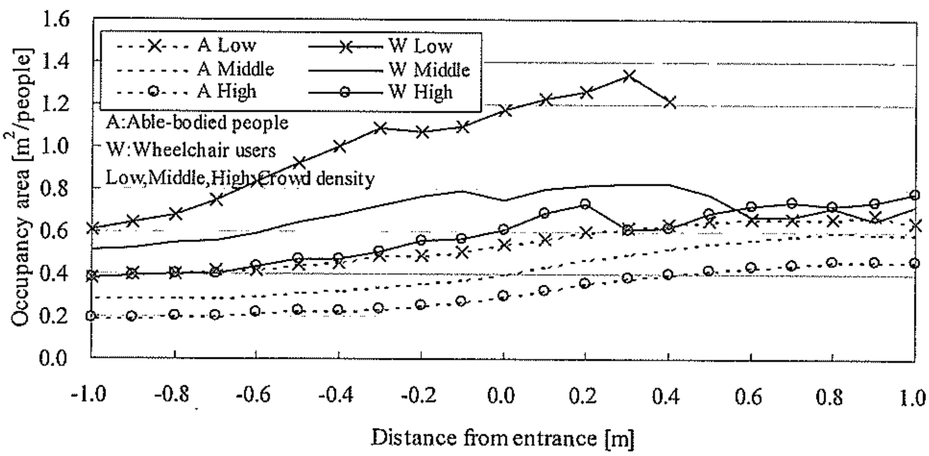

Figure 12 *Occupation area*

3.3 *The flow coefficient decrease by the wheelchair user mixing*

3.3.1 *The flow efficiencies of self-moving type wheelchair and assisted type wheelchair*

Figure 13 shows the relation of the flow coefficient obtained from each mixing rate and the experiment on the type (mixture) with which the self-moving type and, the assisted type, and the self-moving type and the assisted type mixed at the same time. Here, the mixing rate indicates the one shown by the number of people related to the wheelchair. Therefore, even when the same number of wheelchair users are mixed, the mixing rate is different in the self-moving type and the assisted type. The flow coefficient of the crowd including the assisted type wheelchair indicates larger than that of including the self-moving type. Under the condition that the crowd includes the same number of people passes the entrance, the flow efficiency including the assisted type wheelchair is improved.

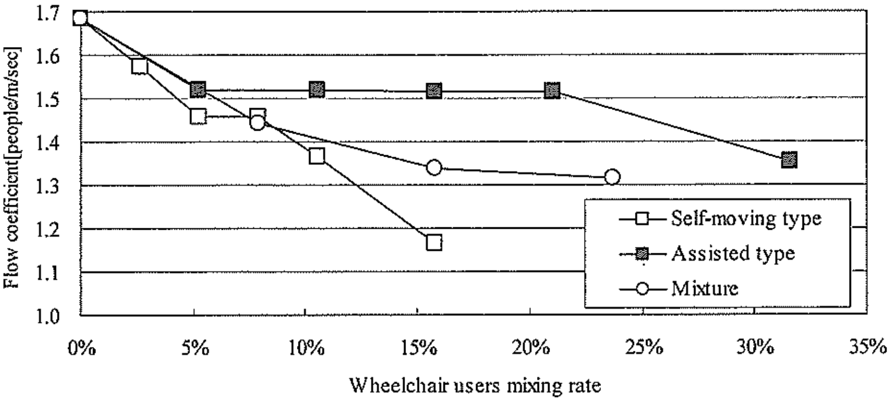

Figure 13 Flow coefficient to mixing rate

3.3.2 Occupation area of the self-moving type wheelchair and the assisted type

The occupation area of each examinee was indicated according to the mixed number in *Figure 14*. The assistant and assisted person travel with less area than the able-bodied people and the self-moving type wheelchair.

When paying attention to the mixed number of wheelchair and its occupation area, the occupation area of the able-bodied people shows almost constant also of the self-moving type and the assisted type have a certain deviation but are also constant. It is thought that the occupation area of each examinee keeps a certain area regardless of the mixing rate of wheelchair users.

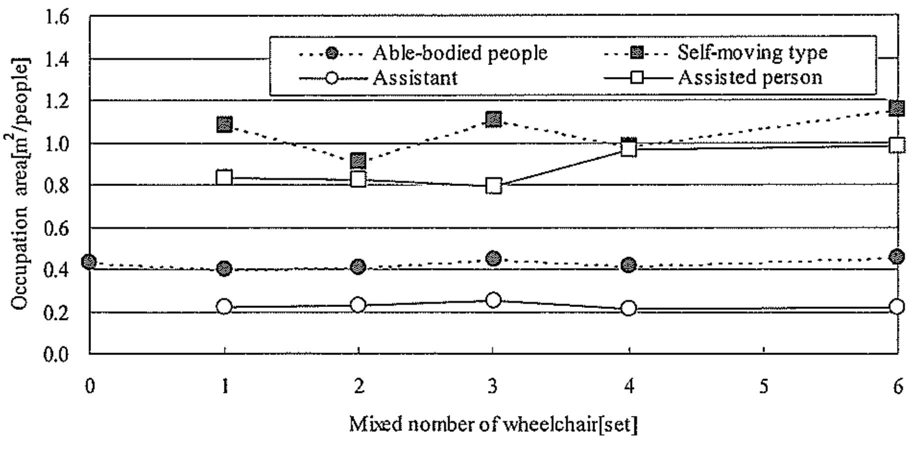

Figure 14 Occupation area to mixed number

3.3.3 *Speed of each examinee*

The relation between the distance from the entrance and speed is shown in *Figure 15* according to the entrance width. Each examinee shows a certain speed though the difference of the speed is seen from the center of the entrance.

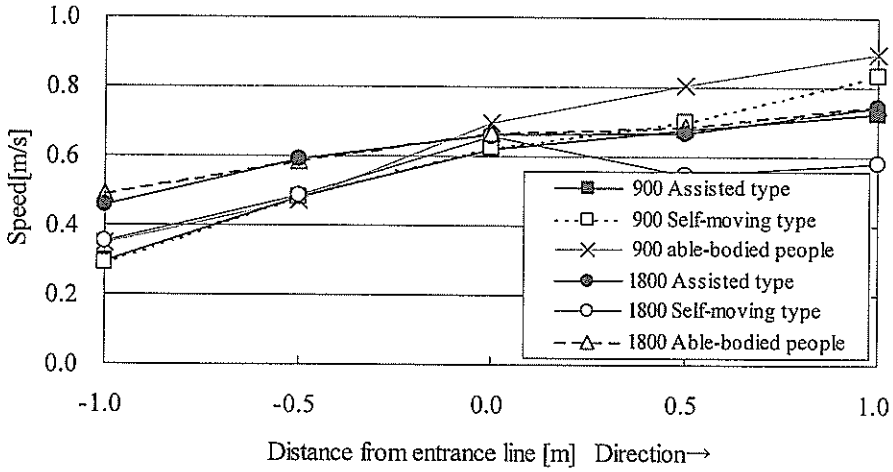

Figure 15 Speed to distance from entrance

3.3.4 *The downward tendency of a flow coefficient*

It becomes clear that both an assistant and an assisted person keep a certain occupation area that is not dependant upon the mixed number of wheelchairs as a flow characteristic of an assisted type. There is no much difference between the speed of the self-moving type wheelchair and the assisted moving type. The assisted type wheelchair as well as the self-moving type can be treated as an element that increases the virtual area in proportion to the mixing rate of then. Then, the relation between the calculated and the measured value from the flow coefficient calculated from the occupation area, the mixing rate and the crowd speed (*Table 1*) in the center of entrance width is shown in *Figure 16-18*. *Figure 16* shows a case mixed with the self-moving type wheelchair, *Figure 17* shows a case mixed with the assisted type wheelchair and *Figure 18* shows the case mixed with both the assisted type and the self-moving type. They indicate an almost similar decreasing tendency of the measured data and the calculated date.

Table 1 Calculating formula and each value

1. Self-moving type

$$N=\frac{V}{A\left(1-\frac{\alpha}{100}\right)+B\left(\frac{\alpha}{100}\right)}$$

N : Flow Coefficient [people/m/s]
α : Self - moving type mixing rate [%]
β : Assisted moving type mixing rate [%]

(Examination 3)

		Average		σ	
		900mm	1800mm	900mm	1800mm
V : Speed	[m/s]	0.57	0.30	0.09	0.05
A : Occupation area of able-bodied people	[m^2/people]	0.26	0.20	0.02	0.03
B : Occupation area of self-miving type	[m^2/people]	0.90	0.75	0.14	0.13

2. Assisted moving type

$$N=\frac{V}{A\left(1-\frac{\beta}{100}\right)+(C+D)\left(\frac{\beta}{100}\right)}$$

3. Self-moving type and assisted type (mixture)

$$N=\frac{V}{A\left(1-\frac{\alpha+\beta}{100}\right)+B\left(\frac{\alpha}{100}\right)+(C+D)\left(\frac{\beta}{100}\right)}$$

(Examination 4)

		Average		σ	
		900mm	1800mm	900mm	1800mm
V : Speed	[m/s]	0.60	0.62	0.08	0.07
A : Occupation area of able-bodied people	[m^2/people]	0.32	0.44	0.02	0.07
B : Occupation area of self-miving type	[m^2/people]	1.22	1.11	0.23	0.26
C : Occupation area of assistant	[m^2/people]	0.17	0.22	0.06	0.11
D : Occupation area of assisted person	[m^2/people]	0.90	0.88	0.15	0.19

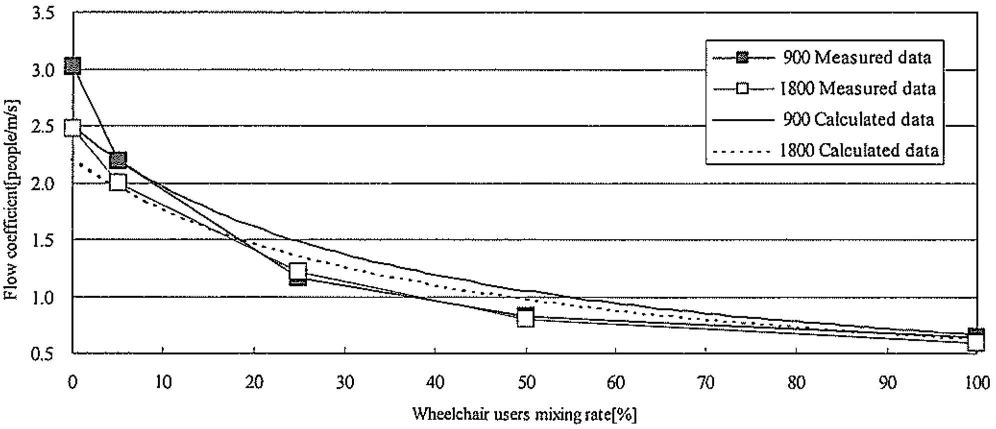

Figure 16 Measured data and calculated data (Self-moving type)

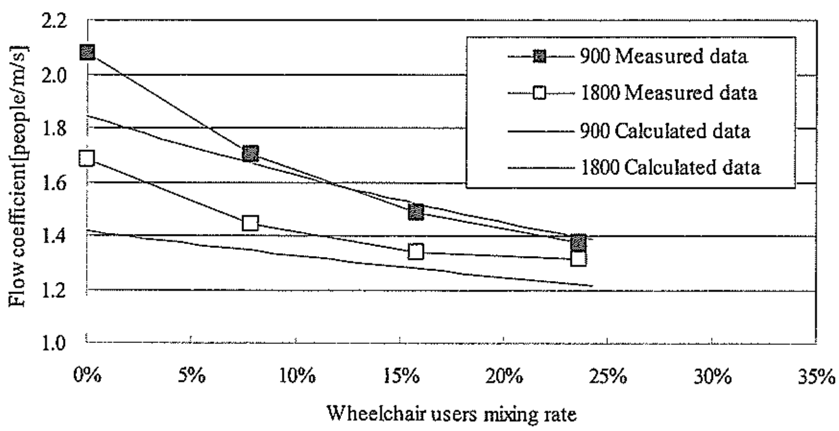

Figure 17 Measured data and calculated data (Assisted moving type)

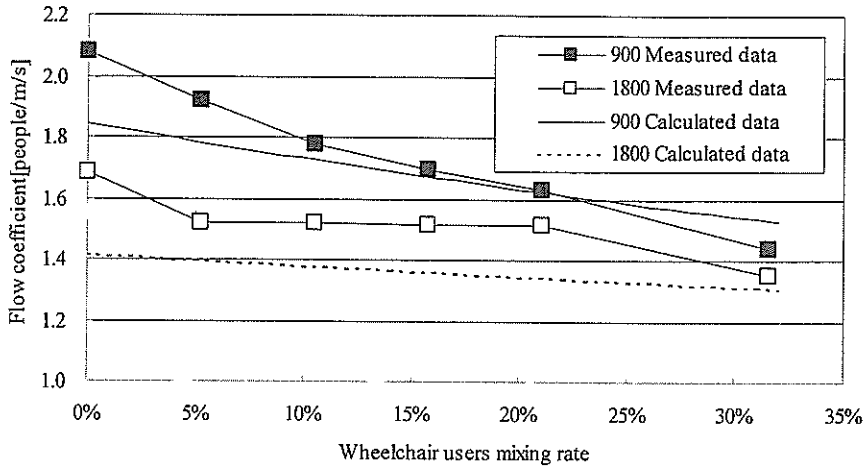

Figure 18 Measured data and calculated data (Mixture)

4. SUMMARY AND DISCUSSION

Through these experiments, conclusions are summarized as follows: However, these conclusions should be considered to be obtained from the experiments that the crowds wore only socks and are instructed.

- In the range that crowd density is 2-8 [people/m^2], the flow coefficient increases as the density increases.
- The flow coefficient decreases as the wheelchair users mixing rate increases in the crowd, but decrease rate of the flow coefficient becomes gradual.
- The entrance width has little effect on the flow coefficient in comparison with other elements.
- The flow of a self-moving type wheelchair is smoother than the assisted moving type.

As the result of this study, we proposed a calculating formula using ergonomic elements, personal occupation area, crowd speed and the wheelchair users mixing rate, which shows almost the same decreasing tendency of flow coefficient as our experiments show. In an evacuation plan, we think that the crowd flow coefficient including wheelchair users can be estimated by using this calculation formula keeping the same safety level as the flow coefficient by the able-bodied people. However, what should be thought of the safety rate of the flow coefficient, what should be thought of the decrease rate of the flow coefficient according to the increase of the wheelchair users mixing rate, further discussions of these are necessary.

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