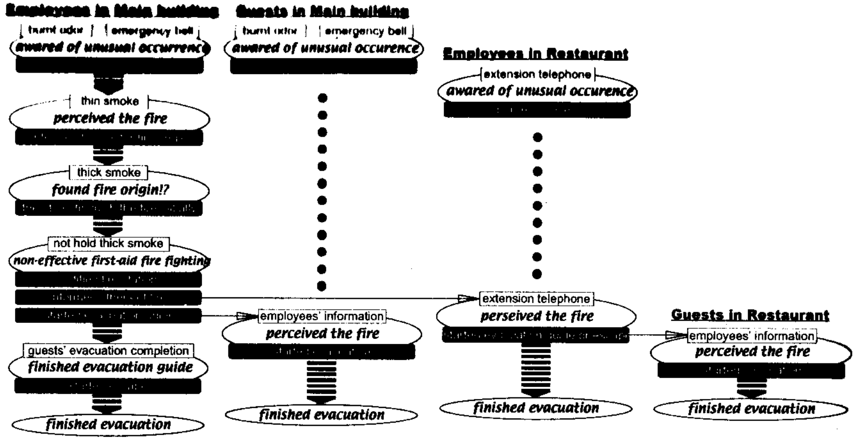

FIGURE 14 Summary for dynamics of the phase of occupants' principal behavior in this fire

sponse to fire taken by these hotel employees.

Despite the complex layout of the building, the fire origin was approximately identified by the information from the automatic fire alarm system. Also, some employees promptly reported the fire situation and took responsive behavior, so the occupants perceived the fire relatively early.

Since the rooms used by the guests were not many and the number of the employees was roughly the same as no. of the guests, the employees could efficiently led and/or directed their guests out of the hotel.

The fire doors closing prevented the corridor from being polluted by the smoke. As a result, the corridors could fulfill their role as escape routes until the occupants evacuated the hotel.

As described above, several factors could be confirmed, including early perception of the fire, employees' evacuation guide for their guests, and the promotion of safe evacuation by ensuring safe routes. It is important to prepare fire safety measures in both hardware and software so that all occupants are able to perceive the fire as quickly as possible.

REFERENCES

1. Jin, T., Watanabe, Y. and Sekizawa, A., "Human Behavior of Guests in the KAWAJI Prince Hotel Fire", Journal of JAFSE, 133, pp.4-16, 1981 (in Japanese)
2. Mizuno, M., Ohmiya, Y. and Takao W., "A Human Behavior in the Tenzankaku Hotel Fire -Interview survey on the hotel employees-", AIJ J. Technol. Des., No. 10, 2000 (in Japanese)
3. Ohmiya, Y., Mizuno, M. and Nakano, M., "Human Behavior in the Hotel Fire at Shirahama -Part 2 The results from questionnaire survey to the hotel employees-", proc. JAFSE, pp. 176-179, 1999 (in Japanese)

Study on Feasibility of Evacuation by Elevators in a High-Rise Building

— A Case Study for the Evacuation in the Hiroshima Motomachi High-Rise Apartments —

AI SEKIZAWA
National Research Institute of Fire and Disaster
3-14-1, Nakahara, Mitaka, Tokyo 181-8633, Japan

SHINJI NAKAHAMA and YUKA IKEHATA
Taisei Corporation
344-1, Nasemachi, Totsuka-ku, Yokohama 245-0051, Japan

MANABU EBIHARA and HIROAKI NOTAKE
Izumi Research Institute, Shimizu Corporation
2-2-2, Uchisaiwai-cho, Chiyoda-ku, Tokyo 100-0011, Japan

ABSTRACT

At a building fire, occupants should usually escape to the ground level or a floor of refuge by stairs, but not by elevators. However, in fact in many of the past fires, not a few people used elevators for their evacuation. Also, it is expected that the number of people who have difficulty to use stairs in evacuation would become larger, since the proportion of aged people in the total population has been rapidly increasing recently in Japan. To consider this situation, we made a simplified elevator service model to evaluate effectiveness of evacuation by elevators, and conducted some case studies in order to examine the feasibility and problems of elevator use for evacuation. As a result of case studies, the diverging point of the advantage of evacuation by elevator to compare with evacuation by stairs appears roughly on 14th floor to 16th floor.

KEYWORDS: evacuation, means of egress, high-rise building, elevator

1. INTRODUCTION

In a situation of a building fire, occupants should usually escape to the ground level or a floor of refuge by stairs, but not by elevators. However, in fact in many of the past fires, not a few people used elevators for their evacuation. In the fire of 20 stories Hiroshima Motomachi High-rise Apartments that occurred in October 28, 1996, more than a half of the total evacuees used elevators from the results of our questionnaire survey. We investigated the likelihood of elevator use in evacuation in relation to the occupants characteristics such as age, living floor height, and so forth [1]. On the other hand, it is expected that the number of people who have difficulty to use stairs in evacuation would become larger in high-rise buildings, since the proportion of aged people in the total population has been rapidly increasing recently in Japan. Also, along with the transition to the performance-based regulation, some countries such as the U.S.A., the U.K., and Australia have started to examine the elevator use in evacuation [2]. Then, we made a simplified elevator service model which is revised from the former version [3] in order to evaluate effectiveness of evacuation by elevators based on the data from the fire in Hiroshima Motomachi High-rise Apartments, and conducted some case studies to examine the feasibility and problems of elevator use for evacuation.

2. OCCUPANTS' EVACUATION IN THE HIGH-RISE APARTMENT FIRE IN HIROSHIMA CITY

2.1 Outline of the Fire and the Apartments

A remarkable fire occurred in the 20 stories high-rise apartments in October 28, 1996 in Hiroshima City. The fire started from an apartment on the 9th floor and spread up to the top floor, 20th floor, very quickly (in less than 30 minutes) by the external flame spread through balconies. As many of the occupants have lived there since it was built in 1972, so about a half of them are aged people at present. In this fire, the occupants were forced to evacuate in smoke filled condition because of unusually quick upward fire spread, but very fortunately there was no fatality with only two injured. The Motomachi high-rise apartments is a 20 stories reinforced fire-resistive building, 172,000 square meter area in total, and contains about 3,000 households. This apartment building has so called skip-floor style design (the style that only even-numbered floors have common corridor to the stairs hall of each block; so people on odd-numbered floors have to use the private stairs down to common corridor of the lower even-numbered floor). Figure 1 shows the floor plan on an even-numbered floor around the 6 block where the fire started.

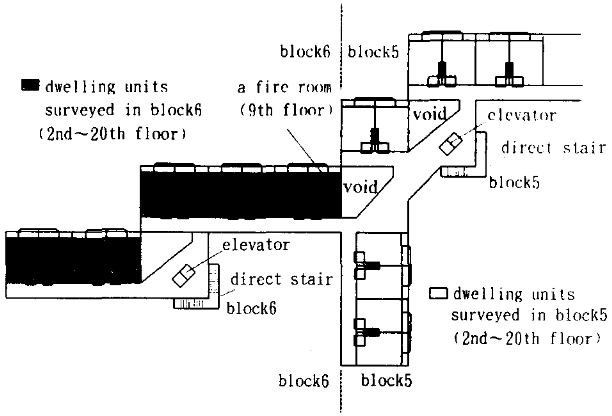

FIGURE 1. Floor plan of the apartments on even-numbered floors.

2.2 Results of Questionnaire Survey on the Evacuation Behavior

Evacuation using elevators is one of the most controversial issues in case of fire in a high-rise building. In this fire, 47% used elevators for their evacuation, while 42% used stairs and 7% used both elevators and stairs from figure 2. The relation between the evacuation routes and the floor height where the respondents live was analyzed, by dividing floors into the groups as the 3rd-5th, 6th-9th, 10th-13th, 14th-17th, and 18th-20th floors respectively. As a result, the occupants on the 6th floor through the 17th floor were more likely to use elevators as the floor they live was higher (see Figure 3). As to the occupants on the 18th-20th floors, no one used the stairs and 89% of them used the elevators in evacuation, if including those who used both the stairs and the elevators. Overall, the higher is the floor they live, the more ratio of the occupants used elevators.

For reference, how frequently the respondents in each floor group usually use the stairs is shown in figure 4. The daily usage of the stairs also shows the tendency that the higher the floor is, the less the occupants use the stairs. It is considered that this usual custom is also associated with choice of an evacuation route as well as floor height as shown in figure 5. Figure 6 shows the use of elevators in evacuation by age group for the total of 55 respondents who were in home at the fire and evacuated down to the ground. The respondents, who are 60 and over, used the elevators slightly more than those who are 59 and under, but there is no meaningful difference between the two age groups because the average age in higher floors is larger than that of lower floors as seen in figure 3.

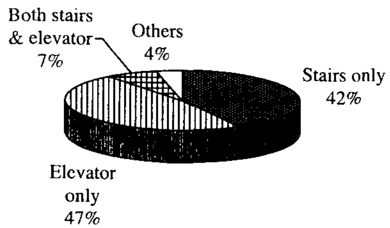

FIGURE 2. Selected means of evacuation. (n=55)

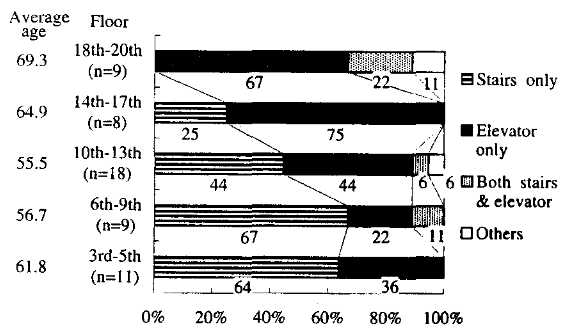

FIGURE 3. Selected means of evacuation by floor. (n=55)

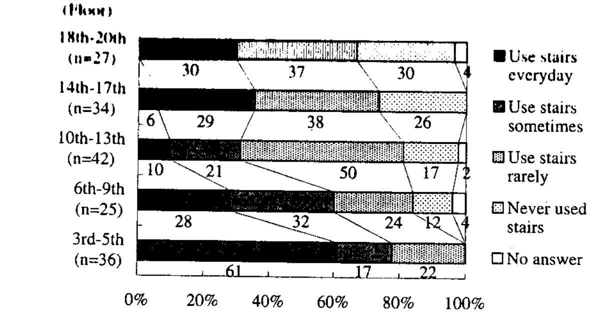

FIGURE 4. Frequency of daily use of stairs by floor. (n=164)

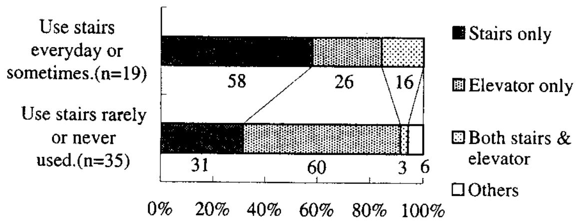

FIGURE 5. Selected means of evacuation by frequency of daily use of stairs. (n=164)

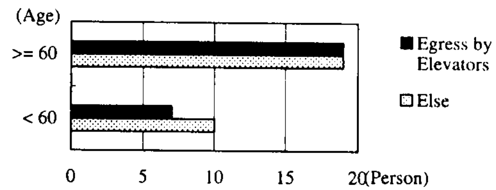

FIGURE 6. Use of elevator in evacuation by age group. (n=55)

3. MODELS FOR EVACUATION BY ELEVATOR AND BY STAIRS

The floor configuration around the elevator hall and stairs in the Motomachi high-rise apartments is shown in figure 7. The model of evacuation by elevator in this report is a revised one based on the former simplified elevator evacuation model[3]. In case studies, both evacuation time by elevator and by stairs was calculated using Monte Carlo method after giving dispersion based on normal distribution on the number of occupants and the ratio of elevator use for evacuation on each floor. 1,000 times of calculations were done for each case.

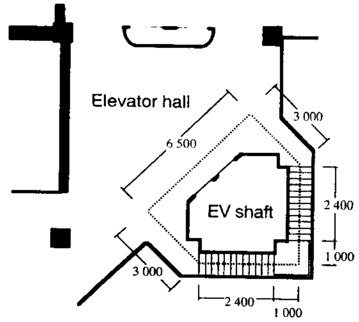

FIGURE 7. Floor configuration around the elevator hall and stairs.

3.1 Transfer Time by Elevator

As the Hiroshima Motomachi high-rise apartment has a skip-floor type design, the elevator stops only on even-numbered floors from the second to the 20th floor, and on the first floor for egress. The elevator transfer time is calculated by the following simplified equation(1).

$$T_m = H_{ij} / V_{elv} + V_{elv} / \alpha \qquad (1)$$

where
T_m: elevator transfer time (s)
H_{ij}: vertical distance between *i*th floor and *j*th floor (m)
V_{elv}: elevator velocity (m/s)
α: elevator acceleration (m/s^2)

3.2 Time for Evacuees to Get On and Off an Elevator

The time for the evacuees to get on and off the elevator is estimated by the following equation(2). The number of evacuees by elevator services is obtained by taking the number of evacuees by stairs from the total number of occupants on each floor.

$$T_e = (P_{fi} - P_{stri}) / (N_{elv} \times W_{elv}) + (T_{op} + T_{cl}) \qquad (2)$$

where
T_e: time for evacuees to get on and off an elevator (s)
P_{fi}: number of occupants on *i*th floor (persons)
P_{stri}: number of evacuees by stairs on *i*th floor (persons)
N_{elv}: flow factor of elevator doors (persons/m·s)
W_{elv}: available elevator door width (m)
T_{op}: opening time of elevator doors (s)
T_{cl}: closing time of elevator doors (s)

Therefore, the evacuation time by elevator is obtained as a total of the transfer time (T_m) and the time for evacuees to get and off the elevator (T_e) as figure 8 shows.

3.3 Model of Evacuation by Stairs

As shown in figure 9, the time for evacuees who live on the highest floor to reach the first floor through the horizontal sections (landings and elevator halls) and stairs is calculated by the following equation(3). Also, the time for all of the evacuees by stairs to flow out to the first floor is estimated by the following equation(4), and then the time by stairs is determined by the following equation(5). Here, the transfer distance on stairs is estimated by the distance horizontally projected.

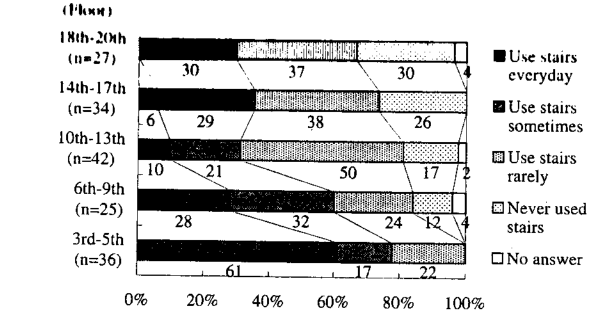

FIGURE 4. Frequency of daily use of stairs by floor. (n=164)

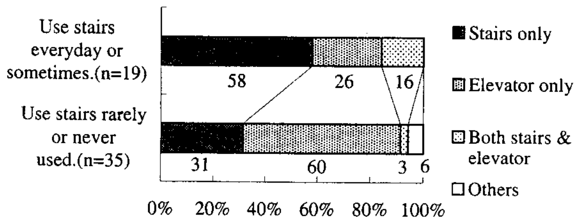

FIGURE 5. Selected means of evacuation by frequency of daily use of stairs. (n=164)

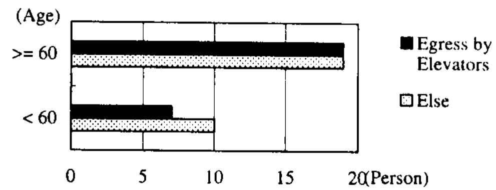

FIGURE 6. Use of elevator in evacuation by age group. (n=55)

3. MODELS FOR EVACUATION BY ELEVATOR AND BY STAIRS

The floor configuration around the elevator hall and stairs in the Motomachi high-rise apartments is shown in figure 7. The model of evacuation by elevator in this report is a revised one based on the former simplified elevator evacuation model[3]. In case studies, both evacuation time by elevator and by stairs was calculated using Monte Carlo method after giving dispersion based on normal distribution on the number of occupants and the ratio of elevator use for evacuation on each floor. 1,000 times of calculations were done for each case.

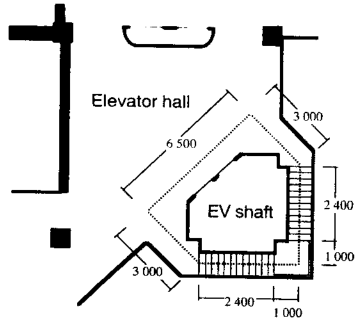

FIGURE 7. Floor configuration around the elevator hall and stairs.

3.1 Transfer Time by Elevator

As the Hiroshima Motomachi high-rise apartment has a skip-floor type design, the elevator stops only on even-numbered floors from the second to the 20th floor, and on the first floor for egress. The elevator transfer time is calculated by the following simplified equation(1).

$$T_m = H_{ij} / V_{elv} + V_{elv} / \alpha \qquad (1)$$

where T_m: elevator transfer time (s)
H_{ij} : vertical distance between *i*th floor and *j*th floor (m)
V_{elv}: elevator velocity (m/s)
α : elevator acceleration (m/s^2)

3.2 Time for Evacuees to Get On and Off an Elevator

The time for the evacuees to get on and off the elevator is estimated by the following equation(2). The number of evacuees by elevator services is obtained by taking the number of evacuees by stairs from the total number of occupants on each floor.

$$T_e = (P_{fi} - P_{stri}) / (N_{elv} \times W_{elv}) + (T_{op} + T_{cl}) \qquad (2)$$

where T_e: time for evacuees to get on and off an elevator (s)
P_{fi}: number of occupants on *i*th floor (persons)
P_{stri}: number of evacuees by stairs on *i*th floor (persons)
N_{elv}: flow factor of elevator doors (persons/m·s)
W_{elv}: available elevator door width (m)
T_{op}: opening time of elevator doors (s)
T_{cl}: closing time of elevator doors (s)

Therefore, the evacuation time by elevator is obtained as a total of the transfer time (T_m) and the time for evacuees to get and off the elevator (T_e) as figure 8 shows.

3.3 Model of Evacuation by Stairs

As shown in figure 9, the time for evacuees who live on the highest floor to reach the first floor through the horizontal sections (landings and elevator halls) and stairs is calculated by the following equation(3). Also, the time for all of the evacuees by stairs to flow out to the first floor is estimated by the following equation(4), and then the time by stairs is determined by the following equation(5). Here, the transfer distance on stairs is estimated by the distance horizontally projected.

$$T_{sv} = \Sigma (L_h / V_h + L_s / V_s) \tag{3}$$
$$T_{se} = \Sigma P_{str} / (N_{str} \cdot W_{str}) \tag{4}$$
$$T_{str} = \max(T_{sv}, T_{se}) \tag{5}$$

where T_{sv}: time needed for moving to the first floor by stairs (s)
L_h: horizontal walking distance (m)
V_h: horizontal walking speed (m/s)
L_s: vertical walking distance (m/s)
V_s: vertical walking speed (m/s)
T_{se}: egress time of flowing out of stairs to the first floor (s)
P_{str}: number of evacuees by stairs on each floor (persons)
N_{str}: flow factor in stairs on the first floor (persons /m·s)
W_{str}: available stairs width on the first floor (m)
T_{str}: evacuation time by stairs (s)

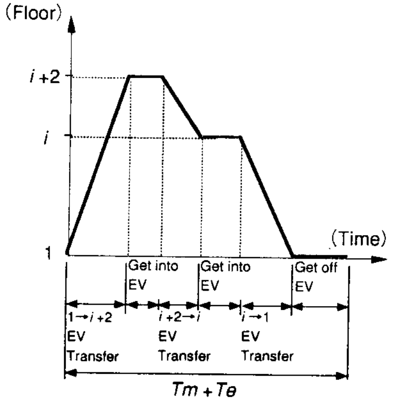

FIGURE 8. Model of evacuation by elevator.

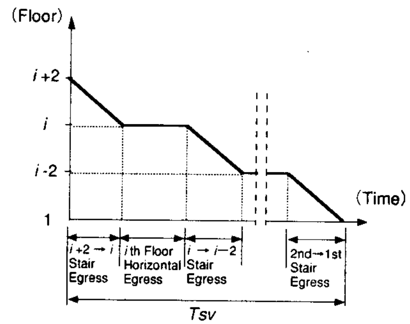

FIGURE 9. Model of evacuation by stairs.

4. CASE STUDY ON EVACUATION IN THE HIROSHIMA MOTOMACHI HIGH-RISE APARTMENTS

4.1 Premises for Case Study

Premises for calculation are as follows.

- Occupants of 18 apartment units on each floor of the 5th and 6th block are objects for case study.
- At the start of evacuation, the occupants stand by at the elevator halls on each floor. The occupants on the odd-numbered floors are ready on the even-numbered floors just under theirs.
- Fire floor is assumed in the second floor, and the floor for egress is to be the first floor.
- No influence by fire is considered.
- The elevator starts from the first floor and moves up directly to the highest floor where there is any evacuee waiting for an elevator. Then, from the highest floor, it stops on every floor that evacuees wait. However, once the elevator is filled up to its capacity, it descends directly to the first floor. The elevator service for evacuation continues until no evacuee waits.

4.2 Setting of dispersion on the number of occupants and the ratio of elevator use

In the case study, three cases are examined as shown in table 1. To set the number of the occupants and the ratio of elevator use in evacuation on each floor, the results of our questionnaire survey[1] are used.

4.2.1 Number of Occupants on Each Floor

For CASE-1 and CASE-2, the average number of occupants on each floor is estimated by multiplying the average number of occupants per apartment unit, 1.08 by the number of apartment units 18 and also by the average presence ratio in-home, 0.47. And, the standard deviation is assumed by considering the gap between the average presence ratio in-home, 0.47 and the real ratio of presence in-home at the fire obtained from the results of our questionnaire survey[1], 0.23. Then, we set its gap, 0.24 as 3 σ value. For CASE-3, fixed number of occupants is used for 20th floor (9 persons) and other even numbered floors (18 persons). These numbers are very close to the average numbers of occupants respectively in the above cases.

4.2.2 Likelihood of Elevator Use

The ratio of elevator use for evacuation are obtained by subtracting the ratio of stairs use from 1.0. In CASE-1, fixed ratio of stairs use is set for the following two patterns, (a) and (b). The pattern (a) is that no evacuee uses stairs for their evacuation, and the pattern (b) is that all evacuees use stairs. In CASE-2, the total average ratio of stairs use in the Hiroshima Motomachi fire, 0.42 is used as the average ratio of stairs use in every floor. In CASE-3, the ratio of stairs use is set by the following recursive equation estimated by the relation between the ratio of daily use of stairs and the floor number.

$$S_{tri} = 1.93 / i - 0.0581 \quad (R^2 = 0.92) \tag{6}$$

where S_{tri}: ratio of elevator use on ith floor
i: even-numbers from 2 to 20

The standard deviation is set to 0.01 so that the ratio of elevator use on the 20th floor 0.04 can be 4 σ limit. The standard deviation is equally set on each floor. And, the necessary parameters needed for calculation shown in table 2 are obtained from the on-site investigation, etc.

TABLE 1. Conditions of case study.

	Number of Evacuees Pfi (Persons)	Elevator Use Ratio for Evacuation
CASE-1	20th Floor : normal(9.14, 1.56)	0 and 1.0
CASE-2	Other Even-numbered Floors : (18.27, 3.11)	normal (i -0.42, 0.11)
CASE-3	20th Floor : 9 Other Even-numbered Floors : 18	i th Even-numbered Floor : normal (1-(1.93/i -0.0581), 0.01)

NOTE: The numebr for i is only an even number from 2 to 20.

TABLE 2 Parameters for case study

Parameters		Value
i* th Floor Height (m)	Hi	2nd Floor: 4.6 4th~20th Floors: 4.6+5.94×(i/2-1)
Capacity of Elevator (Persons)	Pv	17
Elevator Velocity (m/s)	Velv	1.08
Elevator Acceleration (m/s2)	α	0.085
Flow Factor of Getting on (Persons/m·s)	Nelv	1.5
Available Elevator Door Width (m)	Welv	1.0
Opening Time of Elevator Door (s)	Top	3.0
Closing Time of Elevator Door (s)	Tcl	4.0
Horizontal Walking Distance of ith Floor (m)	Lh	7.25×i
Vertical Walking Distance of ith Floor (m)	Ls	3.4×i
Horizontal Walking Speed (m/s)	Vh	0.5
Vertical Walking Speed (m/s)	Vs	0.25
Flow Factor in Stair (Person/m·s) **	Nstr	0.82
Available Stair Width (m) **	Wstr	1.0

*:The numebr for i is only even number from 2 to 20.
**: On the first floor.

5. RESULTS AND DISCUSSION

Figure 10 shows the comparison of evacuation completion time between by elevator use group (Ta) and stairs use group (Tb) for CASE-1. Here, the time (Ta) is the evacuation completion time as for the case that all evacuees use an elevator and the time (Tb) is the evacuation completion time as for the case that all evacuees use the stairs, giving both cases the dispersion of the number of occupants on each floor. As seen in this figure, evacuation by elevator takes some 2.5 times as long as that by stairs on average. This tells that evacuation by elevator services is not necessarily effective, and rather can be less favorable than evacuation by stairs depending upon condition.

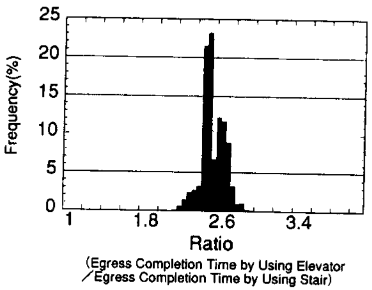

FIGURE 10. Comparison of evacuation completion time between elevator use group and stairs use group for CASE-1.

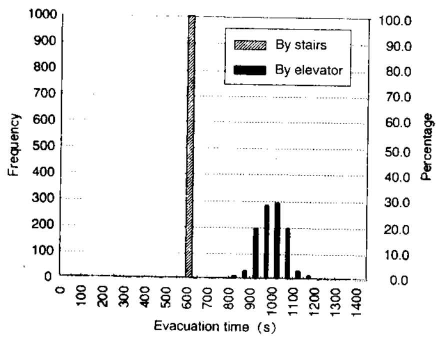

FIGURE 11. Frequency of evacuation completion time by elevator and by stairs for CASE-2.

Figure 11 shows the frequency (in number & %) of evacuation completion time by elevator and by stairs respectively as described in CASE-2. In every case of evacuation by stairs, the evacuation completion time is 562 seconds, because the evacuation time by stairs is determined simply by the transfer time by walk from the 20th floor to the ground floor. The evacuation completion time of elevator use group is close to the normal distribution of Normal (951.3, 58.6). Thus, the average evacuation time of elevator use group is longer by about 390 seconds than that of stairs use group in CASE-2.

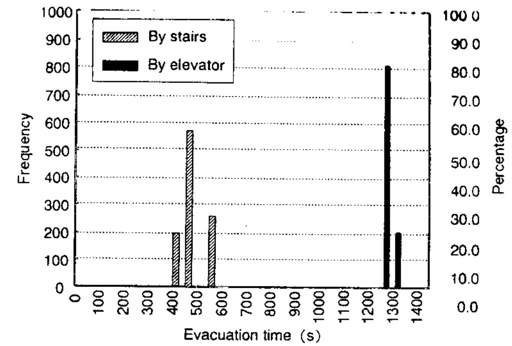

FIGURE 12. Frequency of evacuation completion time by elevator and by stairs for CASE-3.

Figure 12 shows the frequency (in number & %) of evacuation time by elevator and by stairs respectively as for CASE-3. In this case, the ratio of stairs use varies on each floor based on the recursive equation estimated by the relation between the ratio of daily use of stairs and the floor number. So, the upper the floor is, the ratio of stairs use becomes lower, or in other words, the ratio of elevator use becomes higher. As a result, the average of evacuation completion time of elevator use group in CASE-3 is 1,236 seconds that is fairly longer than the average of evacuation completion time of elevator use group in CASE-2. In CASE-3, the evacuation completion time of stairs use group is slightly scattered unlike CASE-2, because there are several cases that no one uses stairs for evacuation on some upper floors.

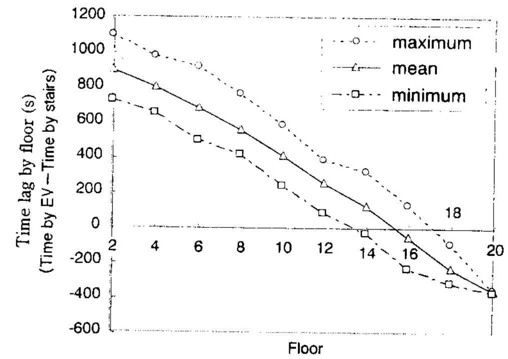

FIGURE 13. Difference of evacuation time between elevator use group and stairs use group on each floor in CASE-2.

Figure 13 shows the difference of evacuation time between elevator use group and stairs use group on each floor in CASE-2. Although the average evacuation completion time of elevator use group is longer by about 390 seconds than that of stairs use group as for a whole building as stated earlier, it is faster to use elevator for evacuation on 20th and 18th floors if examined by evacuation time difference on each floor base. And, on the 12th floor and under, evacuation by stairs is faster than evacuation by elevator even in the case that the evacuation time difference is the minimum.

6. SUMMARY

In this report, evacuation time difference between elevator use group and stairs use group was analyzed by using simplified evacuation models for elevator use and stairs use, based on the data from the investigation on evacuation behavior of the occupants in the real fire in Hiroshima Motomachi high-rise apartments. Although limited in a certain condition of elevator operation described in this report, the diverging point of the advantage of evacuation by elevator in terms of evacuation time to compare with evacuation by stairs appears roughly on 14th floor to 16th floor. In the future, the model improvement and further analysis is needed, considering variety of number of occupants, operating condition of elevators, and the index how to evaluate evacuation efficiency by elevators and/or by stairs.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the courtesy of Hiroshima City Fire Department and the collaboration of Ms. M. Nakano, Mr. K. Kubota, and Dr. Y. Ohmiya in making the data of the investigation on evacuation behavior in the Hiroshima Motomachi high-rise apartments fire.

REFERENCES

1. Sekizawa, A et al., "Occupants' Behavior in response to the High-rise Apartments Fire in Hiroshima City", Proceedings of the First International Symposium on Human Behaviour in Fire, pp.147-156, Belfast, Northern Ireland, 1998.

2. Omiya, Y, et al., "Trend of the Performance-Based Codes and Fire Safety Design Method", Journal of Japan Association for Fire Science and Engineering (KASAI), Vol.49 No.1, pp.22-27, February 1999.

3. Nakahama, S, et al.,"Study on Availability of Evacuation by an Elevator in Consideration on the Aged People -- Example of the Hiroshima Motomachi High-rise Apartment Fire", Journal of Japan Association for Fire Science and Engineering (KASAI), Vol.48 No.3, pp.44-49, June 1998.

A Study for the Fire Safety Planning of the Himeji-jo Castle, A World Heritage

G. MIZUKAMI and Y. HASEMI
Waseda University
Okubo 3-4-1, Shinjuku-ku, Tokyo 169-8555, Japan

T. YAMADA
National Research Institute of Fire and Disaster
Nakahara 3-14-1, Mitaka-City, Tokyo 181-0005, Japan

T. JIN
Fire Protection Equipment & Safety Center of Japan
Toranomon 2-9-16, Minato-ku, Tokyo 105-0001, Japan

ABSTRACT

Himeji-jo castle,a National Treasure and UNESCO World Heritage,is visited by numerous sightseeners every year. In order to derive a fire safety measures for the visitors' safety, 1/25 scale model experiments are carried out to grasp the smoke movement in the castle's main tower. The experiments demonstrate interesting effects of the architectural features of the castle to the smoke movement.

KEYWORDS: smoke movement, historical building, castle building, reduced scale experiment

1. INTRODUCTION

Himeji-jo Castle, a 400 years old National Treasure and UNESCO world heritage, is visited by numerous sightseers from all over the world, around one million a year, and maximum over 6000 daily visitors. There is a record that over 600 persons stood on the 110m^2 top floor , 5.4 person/m^2, at an extreme peak. For this reason, consideration of fire safety is important not only for the protection of the historic building itself but also for the life safety of visitors. The current fire safety measures in the castle building are based on the Fire Service Law with the primary purpose to protect cultural assets by, for example, sprinklers, indoor fireplugs and, fire extinguishers. However, it has not yet been verified whether these measures effectively function for the safety of visitors in the event of an actual fire. Under many