Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Indoor-zoning map on dwelling space safety during an earthquake

S.Okada
Hokkaido University, Japan

ABSTRACT: Considering that ensuring indoor space safety is the key to minimize casualties in dwellings during an earthquake, this research provides the method of "indoor-zoning" of a dwelling by which the casualty risk in each space in the building can be evaluated. As a case study the five-story apartment building damaged in the 1978 Miyagi-ken-oki earthquake was estimated. From this analysis, it is understood that the rate of occupant's casualty should be especially controlled by the furniture arrangement planning and the occurrence time of the earthquake.

1 Introduction

In order to minimize casualties due to earthquakes, a lot of equations for estimating the number of victims at an earthquake have been proposed so far. Most of the equations are constructed on the assumption that casualty occurs as a result of the collapse of building. The representative equation is the following one given by Kawasumi (1954):

$$\text{Number of Death} = 10^{-2} \times H^{1.3}, \quad (1)$$

where H is the number of houses totally collapsed. Like Page et al. (1975), there is no doubt that building collapse is the principal cause of death in earthquake disasters. However, we should pay attention to the fact that people are often injured by interior damage, for example, furniture overturned inside rooms; even if the dwelling itself has no seismic damage. Such damage is conspicuous in developed countries where advanced buildings with high resistivity and ductility occupy an overwhelming percentage of dwellings. Ensuring indoor space safety is a key to reduce casualties in dwellings during an earthquake.

This research provides the method of "indoor-zoning" of a dwelling by which the probability potential of suffering injuries or death at each space inside the building can be assessed.

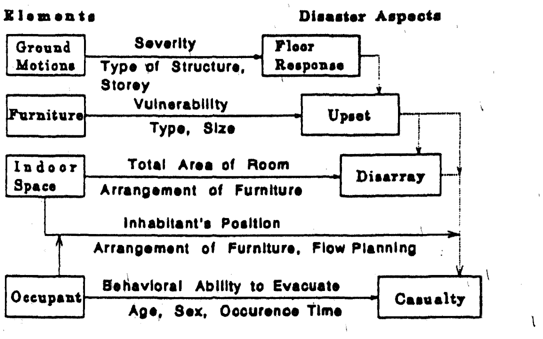

Figure 1. Causal model of occurring casualty in buildings

2. Method for indoor-zoning on casualty risk

2.1 Causal model on the occurrence of casualty in buildings

Figure 1 shows the process of occurring human casualty due to furniture overturned in a room. At the first stage of the process, earthquake ground motions shake the dwellings. Its floor response is related to the building structural type and the stories of houses, as well as the severity of ground motions. Under such a large floor response, some interior damages and vast disarray of objects and furnishings are usually inevitable. In addition to floor response, the turnover probability of furniture should be controlled by such factors as the size of the furniture and whether some extra preventive measures are taken against shaking the furniture down.

Whether the habitants actually get injuries or not due to the furniture overturned must be governed by the disarray of furnishings overturned and their human ability to evacuate from the accident. A measure of disarray of furnishings overturned depends on the total area of the room, the number of furnishings possessed and the interior plan for furniture arrangement etc. Human ability is likely to be influenced by the occurrence time of earthquake and their attributive parameters as age, sex and morbidity. Besides, earthquake casualty should also be controlled by the probability of where they are in the dwelling when the earthquake occurs.

Even in the same dwelling the casualty risk is inhomogeneous over the indoor space and it differs from a time to another. In order to estimate the casualty risk in dwellings, I provide the following equation with some parameters described above:

$$D_i = \mathrm{Prob}[\mathrm{be}|\mathrm{circumstance}] * \Sigma(V_{jk}(I) * (1 - H(I, \mathrm{time}; \mathrm{age}, \mathrm{sex}, \mathrm{morbidity}))) * I, \quad (2)$$

where D_i is the probability of suffering light (i=1) or heavy injury (i=2) due to the furniture overturned. Prob[be|circumstance] stands for the probability of where a habitant is when an earthquake occurs. $V_{jk}(I)$ is the probability of shaking furniture down. The subscript letters, j and k, of V are the damage level of *furniture* and *the type of furniture*, respectively. $V_{jk}(I)$ is a kind of vulnerability function describing the percentage of furniture overturned as a result of experiencing floor response severity, I, represented by the seismic intensity. H() is the human ability to evacuate.

2.2 Description of parameters

Equation (2) can be rewritten as follows:

$$D_i = \mathrm{Prob}[\mathrm{be}|\mathrm{circumstance}] * \mathrm{Pot}[\mathrm{injury}]_i, \quad (2)'$$

and

$$\mathrm{Pot}[\mathrm{injury}]_i = \Sigma V_{jk}(I) * (1 - H()). \quad (3)$$

D_i is the casualty risk and $\mathrm{Pot}[\mathrm{injury}]_i$ means the casualty potential inherent to the indoor space which is characterized by interior plan for furnishings etc. We can estimate $\mathrm{Pot}[\mathrm{injury}]_i$ by the following process.

$\mathrm{Pot}[\mathrm{injury}]_i$ can be obtained at each unit space in the room. Consider a unit space; if the furniture is toppled to the space and/or if the heavy objects fall down to the space, the space has a casualty potential of heavy injury (i=2).

$$\mathrm{Pot}[\mathrm{injury}]_{i=2} = \Sigma V_{jk}(I) * (1 - H()). \quad (4)$$

If the light objects fall down to the space, the space has a casualty potential of light injury (i=1).

$$\mathrm{Pot}[\mathrm{injury}]_{i=1} = \Sigma V_{jk}(I) * (1 - H()). \quad (5)$$

where k is the number of possible furniture damaging the space. If k=n, the definition domain of *$\mathrm{Pot}[\mathrm{injury}]_i$* is

$$0 \leq \mathrm{Pot}[\,]_i \leq n.$$

The higher the value of $\mathrm{Pot}[\,]_i$ is, the more risky the unit space is. D_i and $\mathrm{Pot}[\,]_i$ is calculated as a sum set of heavy and light injuries in reference to the probability of suffering casualty, as shown in Figure 2.

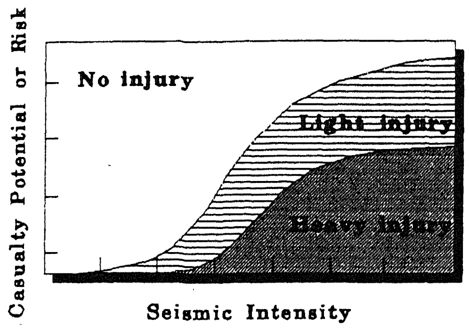

Figure 2. Relation between D_i and $\mathrm{Pot}[\,]_i$ in equation (2) and seismic intensity

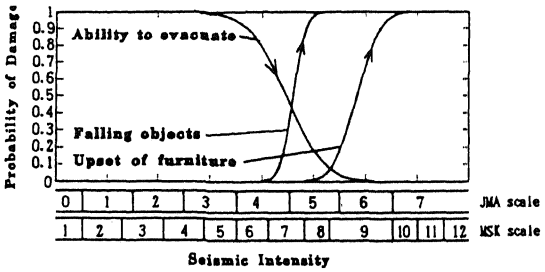

Figure 3. Vulnerability functions on interior damage (after Okada and Kagami(1991))

$V_{jk}(I)$ of the equations (3), (4) and (5) is the vulnerability function of furnishings. Figure 3 shows ones regarding interior damage described by the cumulative damage rate (Okada and Kagami(1991)).

H(I, time; age, sex, morbidity) which means the ability of human behavior to evacuate is shown in Figure 3 . In calculation it is necessary for adjusting the ability by the human attributes such as age, sex and morbidity, and the occurrence time of earthquake. They would differ from one country to another. In this study I adopt the average function in Japan (Figure 4 (Ohta et al.)).

Figure 5 showing the area of a mess of objects accompanied by the upset of furniture, was obtained on the basis of the study of Shodo and Suzuki (1989).

By following the above process, the casualty potential Pot[injury]$_i$ can be estimated at any unit space in a dwelling. The indoor-zoning map on casualty potential can be obtained by applying the drawing technique of contour maps to the Pot[]$_i$ values at every unit space.

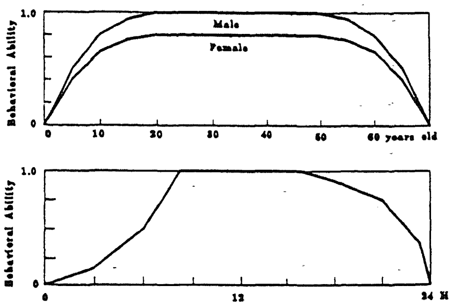

Figure 4. Casualty rates dependent on human attributes (after Ohta et al.)

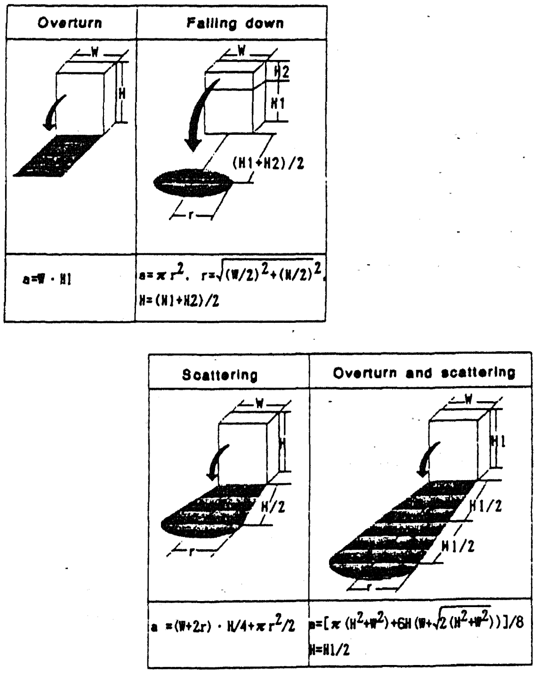

Figure 5. A mess of furnishings overturned

Considering the probability whether occupants stay inside the building in an earthquake, that is, Prob[be|circumstance], we can assess the casualty risk D_i of the equation (2). Prob[] ought to depend on the custom in the country, and his personality and habit. Figure 6 shows variation in occupancy for urban population in Japan, as an example (Coburn et al.(1987)).

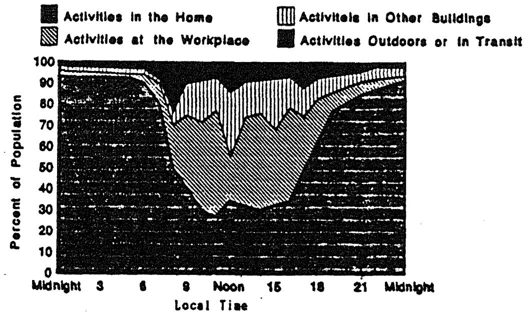

Figure 6. Variation in occupancy for urban population in Japan (after Coburn(1987))

3.Case study of casualty risk assessment

we collected the data on human behavior in five-story apartment buildings damaged in the 1978 Miyagi-ken-oki earthquake by means of interviewing the housewives immediately after the event had occurred. On the basis of the data I try to assess the casualty risk inside the building by following the above method.

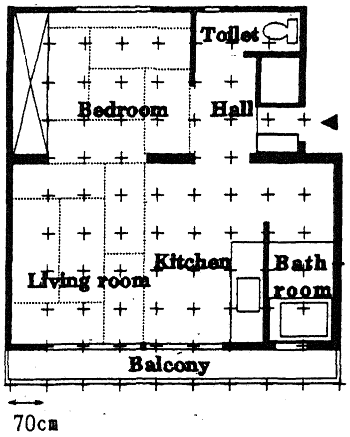

Figure 7. Floor plan of the apartment building

The Miyagi-ken-oki earthquake of the JMA magnitude 7.4 occurred at about 5 P.M. on 12 July 1978. It totally destroyed over 1,000 dwellings and killed about 30 people in the *Miyagi prefecture*, *northern Honshu island*, Japan; where the seismic intensity was 5 on the JMA scale equivalent to 8 on the MSK scale.

The apartment buildings we surveyed were built at the uptown Sendai of the central city in the Miyagi prefecture. Figure 7 displays the floor plan of the apartment building. It that is provided by the Japan Housing Cooperation has a living room, a bedroom, and a kitchen and dinning room. The total floor area of 41.6 m^2, including a balcony, is about half as big as the average one in Japan. According to the seismic intensity survey (Ohashi and Ohta (1980)), the floors of this building were shaken on the severity equivalent to the JMA intensity from 5.3 to 5.8. I assess the casualty risk about a thirty-year-old female occupant in the building under the circumstances.

3.1 Indoor-zoning of casualty potential

Figure 8 shows an example of furniture arrangement in this building. This is the case of Household A that possesses quite a few furniture. Figure 9 depicts the disarray of objects and furniture when all furnishings are overturned. In Figure 10 the values indicate the casualty potential for light or heavy injury, $\mathrm{Pot[injury]}_{l-1+2}$ of the equation (3), estimated at every unit space (=70cm x 70 cm) in the room. These are calculated under the circumstances that the floor is shaken by the severity of 5.8 on the JMA seismic intensity scale. The shaded zones in the figure show the extremely risky ones where the values of $\mathrm{Pot[\,]}_{l-1+2}$ are beyond 0.8, that means the threshold level whether an occupant is injured or not. In case of this house, the floor space in front of the kitchen sink and the hall are quite safer. On the other hand, it looks as if there is the most risky space in a living room. In fact, the housewife living in this house was injured due to the bookshelves overturned in the *Miyagi-ken-oki earthquake. It is a serious* problem that the living room where the occupants usually spend more time is dangerous.

Figure 11 shows variations of the casualty potential in this house according as the severity of the floor response. The point indicates the casualty potential at each unit space. From this figure we can understand that the casualty potential differs from one space to another even in the same room and that more and more the difference is remarkable in proportion to the escalation of floor response. It could give rise to this phenomenon that all the casualty potential converge on the extreme value whether 1.0, which means the highest risk, or 0.0, which means the complete safeness; as highlighted in Figure 11.

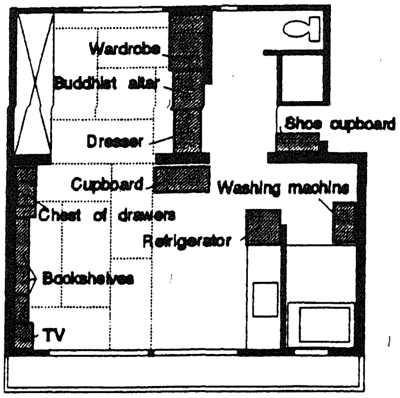

Figure 8. Furniture arrangement in Household A

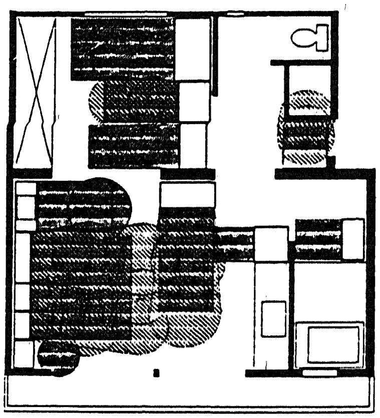

Figure 9. Disarray of objects and furnishings

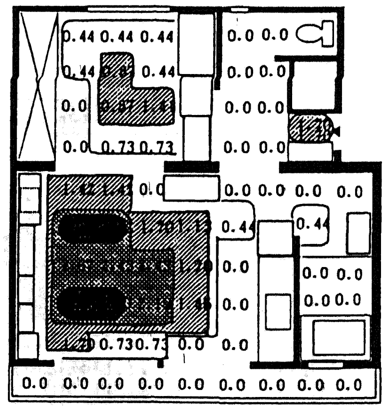

Figure 10. Contour map of casualty potential in Household A

Accordingly, when the floor response is extremely large, each space becomes the alternative one of the highest risk or the complete safeness.

3.2 Casualty risk

In order to develop the casualty risk from the casualty potential, it is necessary for considering Prob[] of equation (2) that the probability of where an occupant is inside the dwelling when an earthquake occurs. Ohashi and Ohta (1980) investigated the housewives' positions just before the quake in the Miyagi-ken-oki earthquake. On the basis of the data, the probability distribution [%] of an occupant's position is obtained in Figure 12. By the reason why the quake occurred at the time, 5:00 P.M., for preparing for their meals, most the housewives stood cooking in front of the kitchen sink. Following the equation (2), I calculated the casualty risk in Figure 12 which means the probability of suffering light or heavy injury with a parameter of floor response.

The solid line in Figure 13, which is given by considering the probability distribution of habitants' existence in Figure 12, shows the casualty risk suffering light or heavy injury just before the quake occurs. Provided 0.8 of the casualty risk is the threshold level whether a person is wounded or not, it is able to suggest that an occupant inside this house would be injured when the floor response becomes over 5.5 on the JMA intensity scale.

Because there is a safety space in front of the kitchen sink in this house, the casualty risk for the Miyagi-ken-oki earthquake shown by the solid line is relatively low. However, if the earthquake had occurred during having a meal, the situation would have become worse. The doted line in this figure is calculated under the circumstances that inhabitants are sitting in the living room which is the most dangerous space in this house. The casualty risk increases over twice as high as one in the Miyagi-ken-oki earthquake. It is necessary for the occupants to take measures to prevent this damage. For example, it is very effective to decrease the number of furniture and to change its arrangement, and to attach heavy furniture to the walls with steel angles and straps (Yanev (1974)). Notice that the walls are strong enough to withstand the moment arising from the shake of the furniture.

An example of the other household B in the same apartment building is shown in Figure 14. This household has less furniture than the previous one. As shown in this figure, a lot of safety space is preserved in this house. Figure 15 is the graph regarding the casualty risk in Household A and Household B for the Miyagi-ken-oki earthquake. This figure suggests that no casualties in Household B should have occurred even if the earthquake

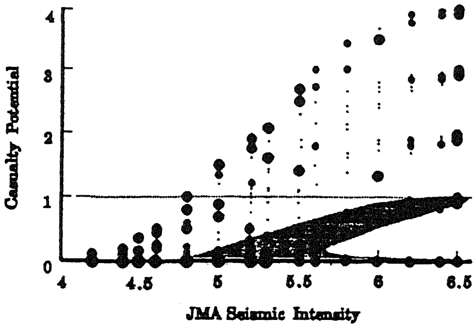

Figure 11. Relation between casualty potential and floor response

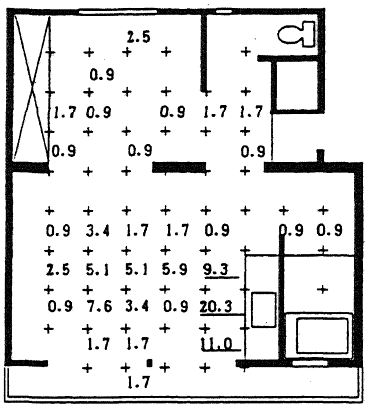

Figure 12. Rate[%] of Occupants' position of housewives just before the Miyagi-ken-oki earthquake

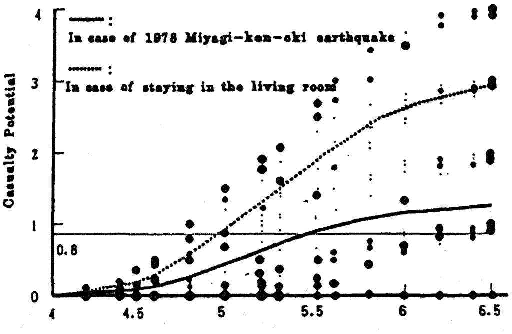

Figure 13. Casualty risk in Household A

had been much larger.

4. Conclusions

This paper provided the way to estimate the casualty risk *inside dwellings*. *Following* the method, I estimated the indoor space safety of the dwelling in the apartment building damaged by the Miyagi-ken-oki earthquake. From the analysis it is shown that the level of casualty potential of suffering injuries differs from one space to another even in the same room and the spatial distribution of its potentiality can be visually understood by means of this method. The results suggest that the rate of casualty should have been controlled a lot by the location of furniture and the occurrence time of the earthquake in the case of this apartment building.

To minimize casualties due to earthquakes, it is important to make indoor space safer as well as to make a building structure itself aseismic. Such a method as proposed in this paper should give us available information on floor planning and furnishings arrangement planning in order to maintain indoor security against earthquakes.

REFERENCES

Coburn A., H. O. Murakami, & Y. Ohta 1987. Factors Affecting Fatalities and Injury in Earthquakes, Chair for Engineering Seismology and Earthquake Disaster Prevention Planning: 1-80.

Kawasumi H. 1954. Intensity and Magnitude of Shallow Earthquakes, Bureau Central Seism. Intern. Ser. A, Trav., Sci.: 19: 99-114.

Ohashi. H. & Y. Ohta 1980. Field survey on human response during and after a large earthquake. Part 2 -Collection of data by interview method and its tentative analysis-. Journ. of the Seism. Soc. of Japan: 33: 199-214 (In Japanese with English abstract).

Ohta Y., H. Kagami, S. Okada, & H. O. Murakami. Earthquake Casualty Assessment Based on Macrostatic and Site-Specific Analyses, In submitting.

Okada S. & H. Kagami 1991. Inventory Vulnerability Functions for Earthquake Evaluation in Terms of Intensity Scale of the Japan Meteorological Agency, Journ. of the Seism. Soc. of Japan: 44: 93-108 (In Japanese with English abstract).

Page R. A., J. A. Blume, & W. B. Joyner 1975. Earthquake shaking and damage to buildings, Science: 189: 601-608.

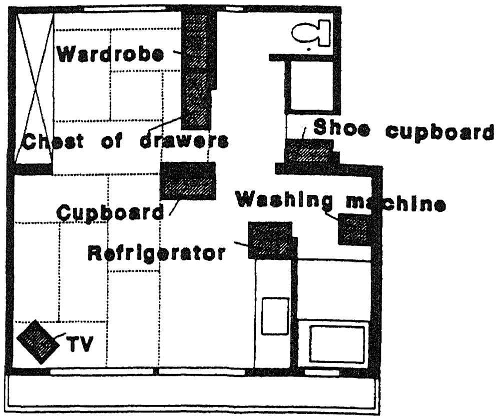

Figure 14. Furniture arrangement in Household B

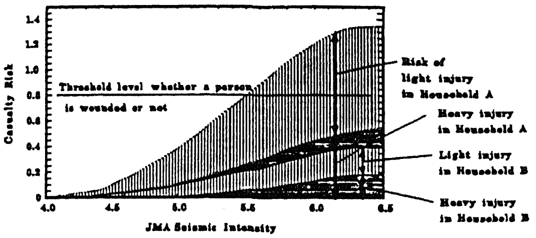

Figure 15. Comparison between Casualty risk in Household A and B

Shodo & T. Suzuki 1989. Proposal of Some Measures to Estimate Earthquake Damages in a Dwelling Space, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan: B: 711-712 (In Japanese).

Yanev, P. 1974. Peace of mind in earthquake country. Chronicle Books.