POTENTIAL SEISMIC RISK ASSESSMENT OF URBAN CITIES BASED ON MACRO-ZONATION CONCEPT

by
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ABSTRACT

This paper describes a potential seismic risk of a city or a group of cities based on the "macro-zonation concept" in which regional macro information such as topography, number of active faults and historical earthquakes, population, accessibility from neighboring cities etc. is considered. In this study, typical cities in Japan are selected and their potential seismic risk is estimated based on statistical data related to the macro information. Also the relationships between the estimated potential seismic risk and the damage observed in Kobe districts damaged by 1995 Hyogoken-Nambu Earthquake are investigated.

INTRODUCTION

In the past, Japan had experienced many earthquakes, typically "1923 Great Kanto Earthquake Disaster", and countermeasures against earthquake disaster which focused mainly on "damage to structures" had been developed. However, due to the 1995 Hyogoken-Nambu Earthquake, more than 5500 people were killed and the importance of the relationship between "structural safety" and "human safety" was highly recognized. This disaster clearly revealed that the current countermeasures were insufficient and that the development of the countermeasure strategy considering a broad array of issues related to the urban earthquake disaster was essentially needed.

In Japan, various schemes for seismic risk assessment have been developed and they have been applied to numerous urban cities especially after the 1995 Hyogoken-Nambu Earthquake. Generally, the micro-zonation concept is applied to conventional risk assessment schemes, where the entire area concerned is divided into numerous unit areas and various data and statistical information at each area are required, and therefore the assessment is significantly time-consuming. As the 1995 Hyogoken-Nambu Earthquake revealed, factors that lead an urban center to devastating damage include a broad aspects related to regional characteristics such as topography, climate, location and number of active faults, inter- and intra-city traffic system, accessibility from neighboring cities, number of typical structures and their seismic capacities, population and land area, economic condition, background history of urban development, experience of past natural disasters etc. However these factors and their interrelation have not been fully considered in the conventional schemes primarily because they are not necessarily available on the micro-zonation basis or should be taken into account from macro viewpoint, i.e., on the macro-zonation basis.

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From this point of view described above, the authors started to develop a methodology which considers, on the macro-zonation basis, factors and their relationship that might cause devastating damage to built environment, emergency response, social and economic activities during and following an earthquake. The main objective of this paper is (1) to identify and quantify key factors related to earthquake damage, (2) to evaluate their contribution to damage, and (3) to develop a methodology to assess the potential seismic risks involved in urban cities and to utilize them for the future earthquake preparedness in a rational way. To examine the effectiveness of macro-zonation concept, this study also aims at categorizing typical cities in Japan into groups depending on the estimated potential hazard in each city.

IDENTIFICATION OF FACTORS RELATED TO POTENTIAL SEISMIC RISK

Potential seismic risk of an urban center needs to be evaluated in an integrated way including damage and/or disruption to built environment, emergency response, social and economic activities etc. during and following an event. *Table 1* shows factors related to potential seismic risk. As shown in the *Table,* two aspects, i.e., 1) those related to natural phenomena and 2) those related to built environment and/or human activities, are considered herein. Chronological description of damage and activities following an event might help understand potential risk. *Table 1* includes direct and physical damage due to an earthquake (phase-1), accessibility from neighboring cities for emergency response (phase-2) and capability of reconstruction from mid- to long-term viewpoint (phase-3), that can be primary candidates for integrated risk assessment. In this paper, phase-1 described above is focused. In the *Table,* factors related to each phase are shown by "◎".

ESTIMATED CITIES AND FACTORS CONSIDERED IN SEISMIC RISK ASSESSMENT

Table 2 shows the estimated cities. Potential seismic risk of 30 cities and 128 wards due to the direct and physical damage was assessed. In the assessment, following factors concerning each city and ward shown "●" in *Table 1* were considered, and their statistical information was utilized.

Aspects Related to Natural Phenomena

Three major items including following sub-items were considered herein.

a) Soft soil rate[1][2]

The soft soil rate in the densely populated districts was calculated, where the following soil conditions were considered.

Swamp, Natural Levee, Alluvial Fan, Seashore Sand, Hill, River Floor, Tideland, Sandbar, Delta, Reclaimed Land, Bank

b) Number of active faults[3]

Active faults within 30km from the city center was considered.

c) Frequency of past earthquakes[4]

Earthquakes with intensity V or larger on JMA scale were considered over the past 400 years.

Aspects Related to Built Environment and/or Human Activities

Nine major items including following sub-items were considered herein.

a) Population and its density[5]

The population during the daytime and nighttime was considered, respectively. The population density was defined as a)/b).

b) Inhabitable area[5]

The area excluding forests and lakes from the total city area was considered.

c) Children and aged population rate[5]

The rate was calculated excluding those aged between 15 through 64 years old.

d) Number of households and their density[5]

The households density was defined as the number of households in 1km^2 inhabitable area.

e) Buildings

Density of wooden and non-wooden buildings constructed before 1971 in 1km^2 inhabitable area and of building coverage (i.e., building-to-land rate) more than 80% were considered.[6]

f) Road condition

Density of roads width less than 6m in 1km^2 inhabitable area was considered.[6]

g) Open space[5]

The number of parks in 1km^2 inhabitable area was considered.

h) Shelter facilities

Capacity demands of hospitals and firemen corresponding to the ratio of population to the number of hospitals and that of households to firemen were considered, respectively[5]

i) Public awareness of seismic risk[7]

The number of earthquakes with intensity equal to or more than I on JMA scale was considered assuming that public awareness might be dependent on the number of felt earthquakes.

CLUSTERING OF CITIES AND WARDS

To investigate the potential seismic risk of direct and physical damage due to an earthquake, *factor analyses*[8],[9] were first made based on the quantified sub-items described above. Then *cluster analyses*[8],[9] were carried out based on the factor analyses to classify cities and wards into clusters.

Methods Employed in Analyses

Factor Analysis[8],[9]

a) Method of factor extraction : Principal Component Analysis

b) Method of factor rotation : Quartimax-Method

c) Method of factor score : Regression Factor Score

Cluster Analysis[8],[9]

In the *cluster analysis*, *grid analyses* were applied.

Results of Analyses

Results of *factor analyses* and *cluster analyses* for representative cities and wards are shown in *Table 3* through *Table 6*. As shown in *Tables 5* and *6*, the number of active faults, frequency of past earthquakes and felt earthquakes were neglected in clustering of wards to simplify the analyses since these data are not necessarily provided in each ward.

ESTIMATION OF POTENTIAL SEISMIC RISK

To estimate the potential seismic risk due to direct and physical damage (phase-1) shown in *Table 1*, the following three criteria were selected; 1) *risk of heavy damage to buildings and resulting fatalities*, 2) *risk of fire and resulting fatalities*, 3) *seismic activities*. It should be noted that all these three criteria were used to estimate the risk for 30 cities while criteria 1 and 2 were used for 128 wards.

Risk of Heavy Damage to Buildings and Resulting Fatalities

Risk of heavy damage to buildings and resulting fatalities may highly depend on the density of buildings, population and households included in category1 as well as soft soil rate in category2 both shown by "★" in *Table 3* through *Table 6*. Therefore, the risk of each city and ward was defined by the following equation (1), and the results are shown in *Table 7* and *Table 8*, respectively.

$$R_B^{(i)} = \Sigma\, CV(i,j) \qquad (1)$$

where,

$R_B^{(i)}$ = *Risk of heavy damaged to buildings and resulting fatalities* for city i or ward i

CV = Class value shown in *Table 4* or *Table 6*

j = Category No., i.e., j=1 or 2

Risk of Fire and Resulting Fatalities

Risk of fire and resulting fatalities may highly depend on density of the wooden buildings/building coverage, population, households and road condition included in category1 shown by "●" in *Table 3* through *Table 6*. Therefore, the risk of each city and ward was defined by the following equation (2), and the results are shown in *Table 7* and *Table 9*, respectively.

$$R_F^{(i)} = CV(i,j) \qquad (2)$$

where,

$R_F^{(i)}$ = *Risk of fire and resulting fatalities* for city i or ward i

CV = Class value shown in *Table 4* or *Table 6*

j = Category No., i.e., j=1

Seismic activities

Seismic activities may highly depend on frequency of past earthquakes and the number of active faults included in category3 shown by "▲" in *Table 3* and *Table 4*. Therefore, the risk of each city was defined by the following equation (3), and the results are shown in *Table 7*.

$$R_S^{(i)} = CV(i,j) \qquad (3)$$

where,

$R_S^{(i)}$ = *Seismic activities* for city i

CV = Class value shown in *Table 4*

j = Category No., i.e., j=3

From the *Table 7* through *Table 9*, the following findings can be obtained.

a) Osaka was classified into group-(8) with respect to *the risk of heavy damage to buildings and resulting fatalities*, group-(5) with respect to *the risk of fire and resulting fatalities* and group-(5) with respect to *the seismic activities, and* was identified to have high potential seismic risk.

b) Kobe damaged by 1995 Hyogoken-Nambu Earthquake was classified into group-(-1) with respect to *the risk of heavy damage to buildings and resulting fatalities* and group-(1) with respect to *the risk of fire and resulting fatalities*, and was identified to have moderate potential seismic risk. However, *the seismic activities* was classified into group-(3) and Kobe was identified to have relatively high *seismic activities*.

c) In general, the potential seismic risk of larger cities was significantly higher than those of smaller cites.

d) Nishinari-ward and Ikuno-ward in Osaka was classified into group-(10) with respect to *the risk of heavy damage to buildings and resulting fatalities* and group-(7) with respect to *the risk of fire and resulting fatalities*, and showed the highest risk among the investigated wards.

e) Nagata-ward in Kobe which was severely damaged by 1995 Hyogoken-Nambu Earthquake was classified into group-(2) with respect to *the risk of heavy damage to buildings and resulting fatalities* and group-(4) with respect to *the risk of fire and resulting fatalities.*

RELATIONSHIPS BETWEEN ESTIMATED POTENTIAL SEISMIC RISK AND DAMAGED CITY

The relationships between the estimated potential seismic risk; 1) *risk of heavy damage to buildings*, and 2) *risk of fire* and the damage observed in Kobe districts damaged by 1995 Hyogoken-Nambu Earthquake[10] are shown in *Fig. 1* and *Fig. 2*. These *Figures* show that the wards with heavier damage during the 1995 Hyogoken-Nambu Earthquake show higher potential risk and the methodology proposed in this study compares well with the observed evidence.

CONCLUDING REMARKS

In this study, typical cities in Japan were selected and their potential seismic risk was estimated based on statistical data related to the macro information. Also the relationships between the estimated potential seismic risk and the damage observed in Kobe districts damaged by 1995 Hyogoken-Nambu Earthquake were investigated. The results can be summarized as follows.

a) The potential seismic risk of larger cities such as Tokyo and Osaka was significantly higher than those of smaller cities.

b) Nishinari-ward and Ikuno-ward in Osaka showed the highest risk among the investigated wards.

c) Nagata-ward in Kobe damaged by 1995 Hyogoken-Nambu Earthquake showed the highest risk in Kobe districts.

d) The estimated potential seismic risk based on the "macro-zonation concept" compares well with the damage observed in Kobe districts.

e) To develop a methodology to estimate the potential seismic risk of cities in a more rational and integrated way, other factors such as accessibility from neighboring cities for emergency response and capability of reconstruction from mid- to long-term viewpoint need to be incorporated.

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Table 1 Factors Related to Potential Seismic Risk)*

Factors Potential Seismic Risk	*Item*	*Sub-Item*	*Damage*	*Access-ibility*	*Recon-struction*
Aspects related to natural phenomena	Topography	Ocean city (Tunami), Basin city etc.	◎	◎	
		Slope area, Man-made area etc.	◎		
	Soil condition	Soft soil rate	◎●		
	Active faults	Number of active faults	◎●		
	Climate	Wind speed, Amount of snowfall, Amount of rainfall etc.	◎	◎	◎
	History of seismic hazard	Frequency of past earthquakes	◎●		
		Number of liquefied areas	◎		
Aspects related to built environment and/or human activities	Population	Population/Population density during daytime and nighttime	◎●		◎
	City area	Inhabitable area	◎●		◎
	Age distribution	Children and aged population rate	◎●		
	Households	Number of households, Households density	◎●		◎
	buildings	Density of wooden and non-wooden buildings constructed before 1971, Density of buildings with building coverage more than 80%	◎●		
	Lifeline	Water, Gas, Electricity etc.	◎		◎
	Hazardous contents	Number of factories	◎		
	Road condition	Density of buildings with the road width less than 6m abutted on the site	◎●		◎
		Road area, Number of lanes etc.	◎		◎
	Traffic	Number of cars, Traffic conditions etc.	◎		◎
	Open space	Number of parks	◎●		◎
	Inter-city traffic and road	Number of lanes, Bridges, Seaports and Airports etc.		◎	
	Neighboring cities	Population/Population density during daytime and nighttime		◎	
		Inhabitable area		◎	
		Economic conditions etc.		◎	
	Accessibility from neighboring cities	Road width, Road area, Number of lanes, Bridges, Seaports, Airports, Ocean city and Basin city etc.		◎	
	Shelter facilities	Number of hospitals and firemen	◎●		◎
		Number of doctors and nurses	◎		◎
	Economic condition	Tax, Annual expenditure etc.			◎
	Public awareness of seismic risk	Number of felt earthquakes	◎●		◎

*) ●-Mark is the estimated factors in this study.

Table 2 Evaluated Cities and Wards

Population (nighttime)[5] *(×1000)*	*City*
less than 300	Ashia, Kawanishi, Totori, Itami, Takaratsuka, Kushiro, Fukui, Miyazaki, Aomori
300～500	Kochi, Takamatsu, Nagano, Nishinomiya, Shizuoka, Nigata, Amagasaki
500～1000	Hamamatsu, Okayama, Kumamoto, Chiba, Sendai(5wards)
1000～2000	Hiroshima(8wards), Fukuoka(7wards), Kyoto(11wards), Kobe(9wards), Sapporo(9wards)
more than 2000	Nagoya(16wards), Osaka(24wards), Yokohama(16wards), Tokyo(23wards)

Table 3 Results of Factor Analysis in Cities

Category	*Sub-item*	*Factor1*	*Factor2*	*Factor3*	*Factor4*
Category1	★●Population density (nighttime)	***0.983***	0.022	0.130	0.067
	★●Households density	***0.997***	0.007	0.020	-0.013
	Population density (daytime)	***0.979***	-0.048	0.160	-0.042
	●Road condition	***0.972***	0.015	0.074	0.056
	★ Density of non-wooden buildings constructed before 1971	***0.946***	0.014	0.178	0.013
	★●Density of wooden buildings constructed before 1971	***0.898***	-0.077	0.414	-0.075
	Population (nighttime)	***0.929***	0.135	-0.288	-0.099
	Population (daytime)	***0.927***	0.085	-0.268	-0.173
	Number of households	***0.903***	0.109	-0.335	-0.165
	Population per hospital	***0.776***	-0.238	0.280	0.245
	Children and aged population rate	***-0.786***	-0.213	0.078	-0.231
	● Density of buildings with building coverage more than 80%	***0.708***	-0.194	0.648	-0.116
	Open space	***0.680***	0.031	-0.079	0.640
Category2	Number of felt earthquakes	-0.114	***0.812***	0.085	-0.264
	★ Soft soil rate	-0.115	***-0.863***	0.085	-0.264
Category3	▲ Frequency of past earthquakes	0.387	0.060	***0.850***	-0.034
	▲ Number of active faults	0.351	0.062	***0.879***	-0.053
Category4	Number of households per fireman	0.006	-0.105	-0.035	***0.904***

★: Sub-items correlated with *risk of heavy damage to buildings and resulting fatalities.*
●: Sub-items correlated with *risk of fire and resulting fatalities.*
▲: Sub-items correlated with *seismic activities.*

Table 4 Clustering of Representative Cities[*)]

City	*Category1*	*Category2*	*Category3*	*Category4*
Sapporo	-1	1	-3	3
Kushiro	-2	-3	1	-2
Aomori	-2	-1	-1	-3
Sendai	-1	-3	1	2
Chiba	-1	-3	-1	1
Tokyo	7	-1	1	-4
Yokohama	2	-3	1	2
Nigata	-1	2	-2	1
Fukui	-2	2	1	-3
Nagano	-2	-6	2	-2
Shizuoka	-2	1	-1	-1
Hamamatsu	-2	-1	-1	-1
Nagoya	2	-1	2	1
Kyoto	2	-1	5	-1
Osaka	5	3	5	-1
Kobe	1	-2	3	3
Totori	-2	3	-2	-4
Okayama	-2	2	-2	-1
Hiroshima	-1	1	-2	2
Takamatsu	-2	3	-2	-2
Kochi	-1	2	-3	3
Fukuoka	1	2	-3	5
Kumamoto	-1	-1	-2	2
Miyazaki	-2	1	-1	-1

[*)] Numerals in the *Table* represent class values of each category shown in *Table 3* for each city.

Table 5 Results of Factor Analysis in Wards

Category	Sub-item	Factor1	Factor2	Factor3	Factor4
Category1	★●Population density (nighttime)	***0.932***	-0.027	0.292	0.019
	★●Households density	***0.917***	-0.078	0.276	0.090
	●Road condition	***0.897***	-0.151	0.226	-0.124
	★●Density of wooden buildings constructed before 1971	***0.966***	0.086	-0.107	-0.075
	★ Density of non-wooden buildings constructed before 1971	***0.645***	-0.028	0.424	0.298
	Population per one hospital	***0.736***	0.040	-0.100	0.471
	●Density of buildings with building coverage more than 80%	***0.853***	0.282	-0.305	0.037
Category2	★ Soft soil rate	0.049	***0.981***	-0.142	-0.002
Category3	Children and aged population rate	-0.294	0.063	***-0.848***	-0.149
	Open space	0.33	-0.091	***0.626***	-0.223
Category4	Population density (daytime)	0.355	-0.010	0.019	***0.879***

★: Sub-items correlated with *risk of heavy damage to buildings and resulting fatalities.*
●: Sub-items correlated with *risk of fire and resulting fatalities.*

Table 6 Clustering of Representative Districts[*)]

City	Ward	Category1	Category2	Category3	Category4
Kobe	Higashinada	-1	1	2	-2
	Nada	2	-3	-1	-1
	Hyogo	3	-1	-2	-1
	Nagata	4	-2	-3	-3
	Suma	-1	-3	-1	-2
	Tarumi	1	-3	2	-2
	Kita	-3	-3	-2	-1
	Cyuo	1	-3	-1	3
	Nishi	-3	-2	-3	-1
Tokyo	Minato	-1	-1	1	7
	Toshima	6	-5	1	2
	Nakano	5	-4	5	-3
	Sinjuku	3	-3	5	-2
	Chioda	-2	-3	-3	12
Osaka	Nishinari	7	3	-1	-3
	Ikuno	7	3	-5	-3
	Asahi	5	3	-1	-2
	Cyuo	-1	1	-1	9
	Kita	-1	3	2	5

*) Nnumerals in the *Table* represent class values of each category shown in *Table 5* for each ward.

Table 7 Grouping of Potential Seismic Risk in Cities

<table>
<tr><th>Direct and Physical Damage</th><th>Group</th><th>City</th></tr>
<tr><td rowspan="17">lower ↑ Risk of heavy damage to buildings and resulting fatalities ↓ higher risk</td><td>-8</td><td>Nagano</td></tr>
<tr><td>-7</td><td></td></tr>
<tr><td>-6</td><td></td></tr>
<tr><td>-5</td><td>Kushiro</td></tr>
<tr><td>-4</td><td>Hamamatsu, Sendai, Chiba</td></tr>
<tr><td>-3</td><td>Aomori</td></tr>
<tr><td>-2</td><td>Kumamoto</td></tr>
<tr><td>-1</td><td>Sizuoka, Miyazaki, Kobe, Yokohama</td></tr>
<tr><td>0</td><td>Fukui, Okayama, Sapporo, Hiroshima</td></tr>
<tr><td>1</td><td>Totori, Takamatdu, Nigata, Kochi, Nagoya, Kyoto</td></tr>
<tr><td>2</td><td></td></tr>
<tr><td>3</td><td>Fukuoka</td></tr>
<tr><td>4</td><td></td></tr>
<tr><td>5</td><td></td></tr>
<tr><td>6</td><td>Tokyo 23-Wards</td></tr>
<tr><td>7</td><td></td></tr>
<tr><td>8</td><td>Osaka</td></tr>
<tr><td rowspan="10">lower ↑ Risk of fire and resulting fatalities ↓ higher risk</td><td>-2</td><td>Totori, Fukui, Nagano, Kushiro, Takamatsu, Okayama, Sizuoka, Hamamatsu, Miyazaki</td></tr>
<tr><td>-1</td><td>Nigata, Chiba, Hiroshima, Sendai, Kumamoto, Sapporo, Kochi</td></tr>
<tr><td>0</td><td></td></tr>
<tr><td>1</td><td>Kobe, Fukuoka</td></tr>
<tr><td>2</td><td>Kyoto, Nagoya, Yokohama</td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>4</td><td></td></tr>
<tr><td>5</td><td>Osaka</td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>7</td><td>Tokyo 23-Wards</td></tr>
<tr><td rowspan="9">lower ↑ Seismic activities ↓ higher risk</td><td>-3</td><td>Sapporo, Kochi, Fukuoka</td></tr>
<tr><td>-2</td><td>Totori, Takamatsu, Hiroshima, Nigata, Okayama, Kumamoto</td></tr>
<tr><td>-1</td><td>Hamamatsu, Sizuoka, Miyazaki, Aomori, Chiba</td></tr>
<tr><td>0</td><td></td></tr>
<tr><td>1</td><td>Fukui, Sendai, Tokyo 23-Wards, Yokohama, Kushiro</td></tr>
<tr><td>2</td><td>Nagoya, Nagano</td></tr>
<tr><td>3</td><td>Kobe</td></tr>
<tr><td>4</td><td></td></tr>
<tr><td>5</td><td>Osaka, Kyoto</td></tr>
</table>

Table 8 Grouping of Risk of Heavy Damage to Buildings and Resulting Fatalities in Wards)*

Group	Ward and City
-6	**Kobe Kita**, Sendai Aoba, Sendai Izumi, Ngano
-5	Tkaratuka, Sapporo Toyohira, Sapporo Nishi, Nigata, Tokyo Chioda, Chiba, Yokohama Izumi, Yokohama Seya, Nagoya Naka, Hiroshima Asakita
-4	**Kobe Suma**, Itami, Sapporo Atsubetsu, Sapporo Teine, Aomori, Sendai Taihaku, Yokohama Totsuka, Yokohama Midori, Kyoto Kita, Yokohama Asahi, Nagoya Meido, Nagoya Midori, Hamamatsu, Kumamoto
-3	Kawanishi, Sapporo Cyuo, Tokyo Nerima, Nagoya Atsuta, Yokohama Sakae, Yokohama Kanazaw, Yokohama Konan, Yokohama Hodogaya, Yokohama Kohoku, Kyoto Saikyo, Nagoya Tenpaku, Hiroshima Higashi
-2	**Kobe Cyuo, Kobe Tarumi**, Ashia, Kushiro, Sendai Miyagino, Tokyo Sibuya, Tokyo Setakaya, Yokohama Kanagawa, Tokyo Minato, Sizuoka, Nagoya Showa, Nagoya Chikusa, Osaka Tennoji, Miyazaki
-1	**Kobe Nada**, Sapporo Shiroishi, Sendai Wakabayashi, Tokyo Mekuro, Tokyo Skinami, Fukui, Nagoya Higashi, Nagoya Moriyama, Kyoto Yamashina, Hiroshima Aki, Hiroshima Asaminami, Hiroshima Saeki, Fukuoka Sawara, Kochi, Totori, Okayama
0	**Kobe Higashinada**, Nishinomiya, Sapporo Higashi, Sapporo Minami, Tokyo Bunkyo, Tokyo Sinjuku, Tokyo Itabashi, Yokohama Turumi, Yokohama Isogo, Yokohama Naka, Nagoya Minato, Nagoya Mizuho, Kyoto Ukyo, Kyoto Sakyo, Kyoto Hushimi, Osaka Cyuo, Hiroshima Nishi, Takamatsu, Fukuoka Higashi, Fukuoka Minami
1	Sappro Kita, Tokyo Toshima, Tokyo Nkano, Nagoya Minami, Nagoya Nakakawa, Kyoto Higashiyama, Osaka Konohana, Osaka Nishiyodogawa, Hiroshima Minami, Fukuoka Jonan, Fukuoka Hakatas
2	**Kobe Hyogo, Kobe Nagata**, Tokyo Sinakawa, Tokyo Kita, Tokyo Cyuo, Tokyo Kodo, Tokyo Edokawa, Yokohama Nshi, Nagoya Nishi, Kyoto Minami, Osaka Kita, Osaka Taisyo, Osaka Abero, Osaka Saminohe
3	Tokyo Ota, Tokyo Katusika, Yokohama Minami, Osaka Sumiyoshi, Fukuoka Cyuo
4	Nagoya Kita, Nagoya Nakamura, Osaka Hukusima, Osaka Hirano, Osaka Turumi, Amagasaki, Hiroshima Naka, Fukuoka Nishi
5	Tokyo Atachi, Tokyo Arakawa, Kyoto Kamigyo, Kyoto Shimogyo, Osaka Yodogawa, Osaka Higashiyodogawa, Osaka Nishi, Osaka Naniwa, Osaka Ninatoku
6	Tokyo Taito, Tokyo Simita, KyotoNakagyo, Osaka Toshima
7	Osaka Joto, Osaka Higashisumiyoshi
8	Osaka higashinari, Osaka Asahi
9	
10	Osaka Ikuno, Osaka Nishinari

*) Larger values in the column of group correspond to higher potential risk, and zero to the average.

Table 9 Grouping of Risk of Fire and Resulting Fatalities in Wards)*

Group	Ward and City
-3	**Kobe Kita**, Sendai Izumi, Sapporo Nisi, Chiba, Niikata, Hamamatsu, Sapporo Teina, Aomori, Sendai Taihaku, Sizuoka, Sendai Miyagino, Miyazaki, Kushiro, Totori, Okayama, Sendai Wakabayashi, Fukui, Sapporo Higasi, Nagoya Minato, Sapporo Minami, Sapporo Kita
-2	Takarazuka, Kawanisi, Sendai Aoba, Nagano, Sapporo Toyohiras, Tokyo Chiyoda, Yokohama Izumi, Sapporo Atsubetsu, Kumamoto, Yokohama Totsuka, Yokohama Midori, Nagoya meito, Nagoya Midori, Kyoto Saikyo, Yokohama Kohoku, Nagoya Tenpaku, Yokohama Sakae, Kouchi, Hiroshima Aki, Hiroshima Asaminami, Fukuoka sawara, Sapporo Shiroishi, Hiroshima Saeki, Nagoya Moriyama, Takamazu, Fukuoka higasi, Kyoto Hushimi, Yokohama Naka, Osaka konohana, Nagoya Nakagawa
-1	**Kobe Higashinada, Kobe Suma**, Ashia, Nishinomiya, Itami, Tokyo Edokawa, Tokyo Minato, Tokyo Koudo, Tokyo Chuou, Yokohama Isogo, Yokohama Seya, Yokohama Turumi, Yokohama Asahu, Yokohama Kanazawa, Yokohama Konan, Yokohama Hodogaya, Yokohama Kanagawa, Nagoya Naka, Nagoya Minami, Nagoya Atuta, Kyoto Kita, Kyoto Minami, Kyoto Sakyo, Nagoya Nishi, Osaka Kita, Osaka Tisyo, Osaka Cyuou, Osaka Nshiyodogawa, Osaka Saminoe, Hiroshima Nisi, Hiroshima Higasi, Fukuoka Jonan, Hiroshima Minami, Fukuoka Hakata, Fukuoka Minami
1	**Kobe Chuou, Kobe Tarumi**, Amagasaki, Sapporo Cyuou, Tokyo Katusika, Tokyo Ota, Tokyo Nerima, Tokyo Atachi, Yokohama Nishi, Nagoya Kita, Nagoya Nkamura, Nagoya Showa, Nagoya Chikusa, Nagoya Higashi, Nagoya Mizuho, Kyoto Yamasina, KyotoUkyo, Osaka Turumi, Osaka Nishi, Osaka Naniwa, Osaka Minatoku, Hiroshima Naka, Fukuoka Cyuo
2	**Kobe Nada**, Tokyo Sibuya, Tokyo Setakaya, Tokyo Itabashi, Yokohama Minami, Kyoto Higashiyama, Osaka tennoji, Osaka Hirano, Osaka Yodogawa, Osaka Higashiyodogawa
3	**kobe Hyogo**, Tokyo Taito, Tokyo Simita, Tokyo Mekuro, Tokyo Sukinami, Tokyo Bukyo, Tokyo Sinjuku, Tokyo Sinakawa, Tokyo Kita, Kyoto Kamigyo, Kyoto Shimogyo, Osaka Hukusima, Osaka Tishima, Fukuoka Nishi
4	**Kobe Nagata**, Osaka Sumiyoshi, Osaka Joto, Osaka Higashisumiyoshi
5	Tokyo Nakano, Osaka Asahi
6	Tokyo Toshima, Osaka Abeno, Osaka Higashinari
7	Osaka Ikuno, Osaka Nishinari

*) Larger values in the column of group correspond to higher potential risk.

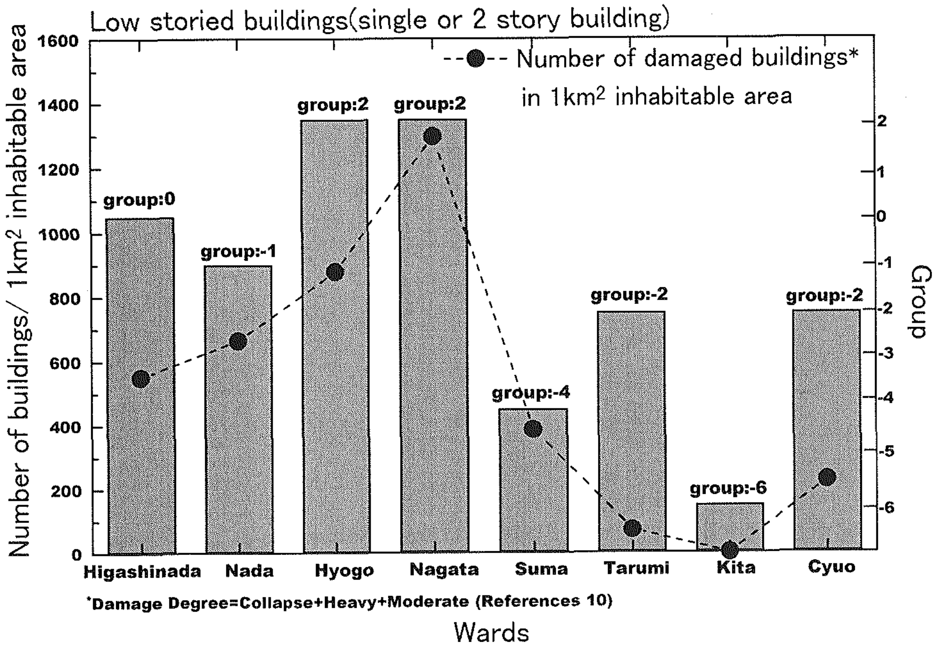

Fig. 1 Relationships between Risk of Heavy Damage to Buildings and Damage Observed in Kobe Districts Damaged by 1995 Hyogoken-Nambu Earthquake[10]

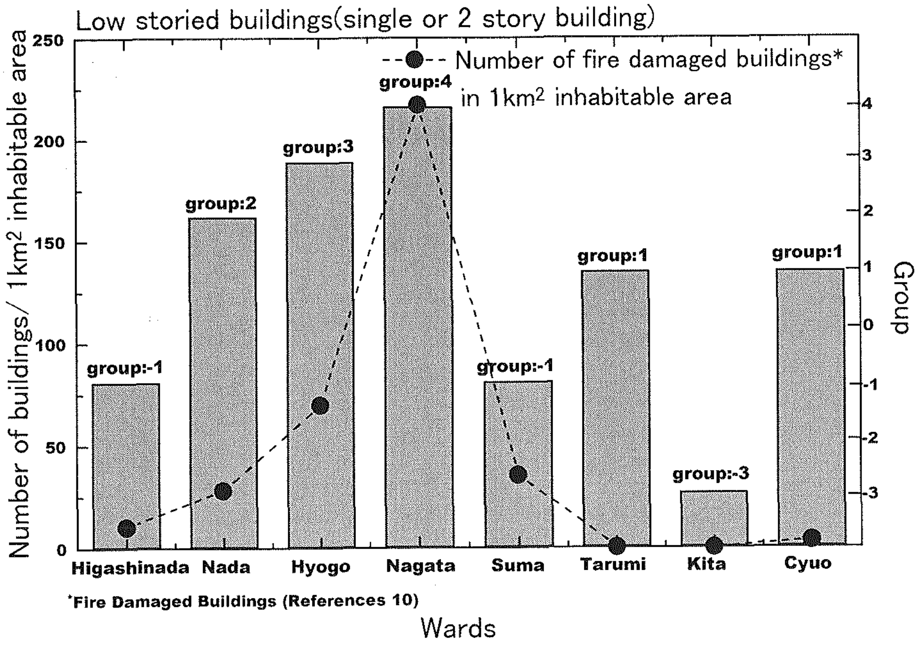

Fig. 2 Relationships between Risk of Fire and Damage Observed in Kobe Districts Damaged by 1995 Hyogoken-Nambu Earthquake[10]