POTENTIAL SEISMIC RISK ASSESSMENT OF URBAN CITIES IN JAPAN CONSIDERING THEIR REGIONAL CHARACTERISTICS

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SUMMARY

In Japan, various schemes for seismic risk assessment have been developed and applied to numerous urban cities especially after the 1995 Hyogoken-Nambu Earthquake. In general, regional characteristics such as soil conditions, buildings conditions, open-space areas, fire-resistive building ratio, building-to-land ratio, etc. are mainly taken into account in the conventional seismic risk assessment from the micro point view, where the entire area concerned is divided into numerous unit areas. However, as the 1995 Hyogoken-Nambu Earthquake revealed, in order to assess the potential seismic risk involved in urban cities and to utilize them for the future earthquake preparedness measures in a rational way, it is essential to consider broad array of issues related to regional characteristics that had not been taken into account in the conventional seismic risk assessment. This study proposed a methodology to estimate potential seismic risk of urban cities based on their regional characteristics. Regional characteristics included macro information such as topography, climate, location of active faults, regionally dependent building types and their seismic capacity, experience of past earthquake disasters, background history of urban development, inter-city traffic system, accessibility from neighboring cities, etc. as well as micro information taken into account in the conventional seismic risk assessment. The methodology was applied to typical urban cities in Japan, and its applicability to assess the potential seismic risk was also discussed herein.

INTRODUCTION

In Japan, various schemes for seismic risk assessment have been developed and applied to numerous urban cities especially after the 1995 Hyogoken-Nambu Earthquake. In general, the damage to built environment directly after an earthquake taken into account the regional characteristics such as soil conditions, buildings conditions, open-space areas, fire-resistive building ratio, building-to-land ratio, etc. is mainly estimated in the conventional seismic risk assessment from the micro point view, where the entire area concerned is divided into numerous unit areas. However, as the 1995 Hyogoken-Nambu Earthquake revealed, in order to assess the potential seismic risk involved in urban cities and to utilize them for the future earthquake preparedness measures in a rational way, it is essential to consider broad array of issues related to regional characteristics that had not been taken into account in the conventional seismic risk assessment.

This study proposed a methodology to estimate potential seismic risk involved in urban cities based on their regional characteristics. Regional characteristics included topography, climate, location of active faults, regionally dependent building types and their seismic capacity, experience of past earthquake disasters, background history of urban development, inter-city traffic system, accessibility from neighboring cities, etc. that had not been fully considered in the conventional seismic risk assessment as well as soil conditions, buildings conditions, width of roads abutted on the site of buildings, open-space, building-to-land ratio, etc. taken into account in the conventional seismic risk assessment. Also typical urban cities in Japan are selected and their potential seismic risk based on the proposed methodology is estimated, and the relationships between

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the estimated potential seismic risk and the damage observed in Kobe districts damaged by 1995 Hyogoken-Nambu Earthquake are investigated.
In this paper, regional characteristics which is common over several cities, sometimes prefectures, such as wind map, active faults map, seismic risk map, snow map, etc. are referred to as *Macro Information*. On the other hand, regional characteristics which is localized in some part of a city, such as soft soil ratio, number of wooden buildings, number of open-space, etc. are referred to as *Micro Information*.

DETERMINATION OF CRITERIA TO EVALUATE POTENTIAL SEISMIC RISK AND CLASSIFICATION OF RESIONAL CHARISTISTICS RELATED TO THEM

Figure 1 shows the relationships between the earthquake disaster and interactive effects based on the typical earthquakes experienced in Japan. As shown in **Figure 1**, the earthquake disaster has not only one phase of damage to built environment directly after an earthquake but also phases dependent on human activities. Especially in the 1995 Hyogoken-Nambu Earthquake, some phases of earthquake disaster such as difficulties of inter- and intra-city rescue for emergency response, and of reconstruction from the mid- to long-term viewpoint are pointed out.

Earthquake disaster is deeply related to the various phenomena and complicated as shown in **Figure 1**. In this study, in order to simplify the subsequent discussions, typical phenomena related to earthquake disaster shown in italic letters of **Figure 1**, which are integrated from the various phenomena within each time-dependent pattern, are derived. Then based on the derived typical phenomena, the following criteria to evaluate the potential seismic risk as shown bellow with underlines are determined.

(Phase-1) Before an earthquake: <u>*Risk of Seismic Activities*</u> (referred to as R_S subsequently)
(Phase-2) Directly after an earthquake: 1) <u>*Risk of Damage to Buildings*</u> and 2) <u>*Risk of Fire*</u> and (referred to as R_B, and R_F subsequently)
(Phase-3) Emergency response stage: 1) <u>*Risk of Refuge Difficulties*</u>, *2)* <u>*Capability of Rescue within Intra-City*</u> and 3) <u>*Accessibility from Neighboring Cities*</u> (referred to as R_{REF}, C_{RES} and C_A subsequently)
(Phase-4) Mid- to long-term after an earthquake: <u>*Capability of Building Reconstruction*</u> (referred to as C_R subsequently)

Table 1(a) and **(b)** show the regional characteristics related to the potential seismic risk, i.e. R_S, R_B, R_F, R_{RES}, C_{RES}, C_A and C_R, of urban cities in phase-1 through phase-4 described above. Each characteristics which appears

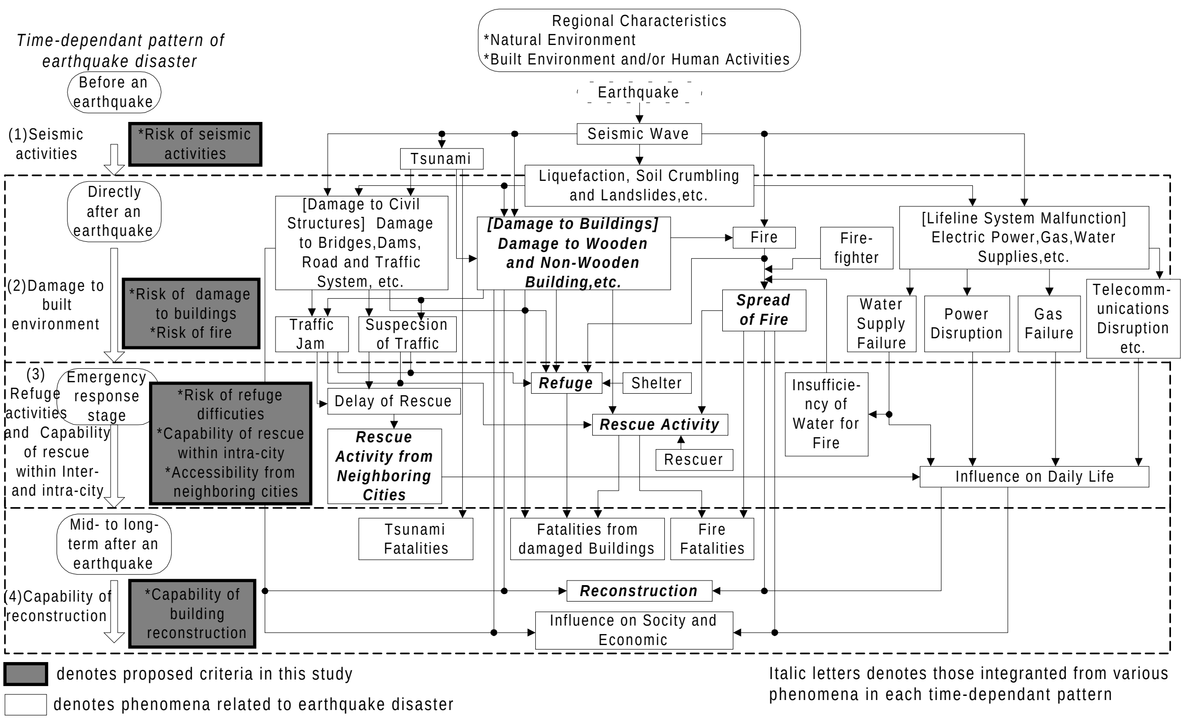


Figure 1: Relationships between earthquake disaster and interactive effects based on the typical earthquakes experienced in Japan.

in **Table 1** is characterized based on Macro and Micro information which, as mentioned above, are referred to as regional characteristics which is common over several cities, sometimes prefectures, and which is localized in some part of a city, respectively. These characteristics are derived from past earthquake disaster experiences in Japan such as 1891 Nobi, 1923 Kanto, 1978 Miyakiken-oki and 1995 Hyogoken-Nambu earthquakes, etc. As shown in **Table 1**, the potential seismic risk is deeply related to the various regional characteristics including *Macro Information* as well as *Micro Information*.

Table 1(a): Regional characteristics related to potential seismic risk of urban cities

Phase	Crit-eria	Summarized and classified regional characteristics: Item	Summarized and classified regional characteristics: Sub-Item [Ref. of statistical data]	Detailed data
Phase-1	R_S	History of seismic hazard*)	Frequency and location of past damaging earthquakes centered on off-coastal and inland area of Japan [Usami, 1996]	[RC_{S1}]:Number of past+) damaging earthquakes++) centered on off-coastal of Japan, [RC_{S2}]:Number of past+) damaging earthquakes++) centered on inland of Japan, [RC_{S3}]:Number of affecting actives faults within 30km from the city center) +) 590 through 1995, ++) Intensity V or larger on JMA scale
		Active faults*)	Number of affecting active faults [RGAFJ, 1995]	
Phase-2	R_B	Soil conditions	Soft soil (Alluvium, Delta, Reclaimed Land, Tideland, Fan)ratio [FRIFDA, 1996]	[RC_{B1}]:Number of wooden buildings with tiled roofing constructed before 1981, [RC_{B2}]:Number of wooden buildings without tiled roofing founded soft soil constructed before 1981, [RC_{B3}]:Number of non-wooden buildings founded on soft soil constructed before 1971, [RC_{B4}]:Number of wooden buildings founded on soil likely to cause liquefaction and land slide, etc. constructed after 1981, [RC_{B5}]:Number of non-wooden buildings founded on soil related to liquefaction and land slide, etc constructed after 1971
			Soil ratio likely to cause liquefaction and land slide, etc (Delta, Filled up Land, Reclaimed Land, Tideland, Developed Land, Seashore Sand, Natural Levee, Fan, Swamp) [FRIFDA, 1996]	
		Buildings conditions	Wooden buildings constructed before 1981 [SBSC, 1993]	
			Non-wooden buildings constructed before 1971 [SBSC, 1993]	
		Regionally dependent building types*)	Roof types, Amount of walls, Foundation type [Field survey, 1998]	
		Background histories of urban development*)	Relationships between past and present land condition[Yamakuchi et al., 1980]	
	R_F	Fire spread factors	Wooden buildings [SBSC, 1993]	[RC_{F1}]:Number of wooden buildings (with building coverage more than 60% and abutting on a less than 6m wide road) causing fire spread, [RC_{F2}]: Average wind speed during past 30years, [RC_{F3}]: Ratio of wooden buildings causing fire spread to fire-resistive building, [RC_{F4}]: Ration of wooden buildings causing fire spread to buildings abutting on a more than 6m wide road, [RC_{F5}]: Ration of wooden buildings causing fire spread to a city park, [RC_{F6}]: Ration of wooden buildings causing fire spread to a fire fighter
			Buildings with building coverage more than 60% [SBSC, 1993]	
			Buildings abutting on a less than 6m wide road [SBSC, 1993]	
			Wind speed*) [JMA, 1998]	
		Fire prevention factors	Buildings abutting on a more than 6m wide road [SBSC, 1993]	
			Fire-resistive buildings [SBSC, 1993]	
			Open spaces [SBSC, 1995]	
			Capacity of fire fighting [FDA, 1995]	
Phase-3	R_{REF}	Refuge road conditions	Buildings abutting on a less than 6m wide road [SBSC, 1993]	[RC_{REF1}]:Number of buildings abutting on a less than 6m wide road, [RC_{REF2}]:Ration of population to a city park, [RC_{REF3}]: Ration of population to a school building
		Shelter facilities	Parks, school buildings and others facilities [SBSC, 1995]	

*): Regional characteristics related to *Macro Information* (Others are related to *Micro Information*)

Table 1(b): Regional characteristics related to potential seismic risk of urban cities

Phase	Crit-eria	Summarized and classified regional characteristics		Detailed data
		Item	Sub-Item [Ref. of statistical data]	
Phase-3	C_{RES}	Capability of rescue	Buildings abutting on a less than 6m wide road [SBSC, 1993]	[RC_{RES1}]:Number of Buildings abutting on a less than 6m wide road, [RC_{RES2}]:Ration of population to a fire fighter, [RC_{RES3}]: Ration of population to a hospital, [RC_{RES4}]: Ration of population to a park, [RC_{RES5}]: Ration of population to a school
			Rescuer [FDA, 1995]	
			Medical facilities [SBSC, 1995]	
		Rescue center	Parks, school buildings and others facilities [SBSC, 1995]	
	C_A	Scale of Supporting city*)	Population of supporting city [SBSC, 1995]	[RC_{A1}]:Population of support city, [RC_{A2}]: Number of land traffic system, [RC_{A3}]: The nearest distance from city center to seaport, [RC_{A4}]: The nearest distance from city center to airport
		Inter-city traffic system*)	Land, sea and air traffic system [SBSC, 1995][PCTM, 1997]	
Phase-4	C_R	Economic conditions and household of the aged	Low income household[SBSC, 1993]	[RC_{R1}]: Ratio of household with a year income less than 3 million yen, [RC_{R2}]: Ratio of household of the aged, [RC_{R3}]: Rented houses ratio, [RC_{R4}]:Owned houses ratio, [RC_{R5}]: Ration fo wooden buildings constructed before 1971, [RC_{R6}]: Ratio of buildings with site area less than 50m^2, [RC_{R7}]: Ration of Buildings abutting on a less than 4m wide road
			Household of the aged[SBSC, 1993]	
		Owned and rented houses	Owned houses [SBSC, 1993]	
			Rented houses [SBSC, 1993]	
		City area conditions	Buildings with the site area less than 50m^2 [SBSC, 1993]	
			Buildings abutting on a less than 4m wide road [SBSC, 1993]	
			Wooden buildings constructed before 1971 [SBSC, 1993]	

*): Regional characteristics related to *Macro Information* (Others are related to *Micro Information*)

POTENTIAL SEISMIC RISK ASESSMENT

Figure 2 shows the procedures of potential seismic risk assessment considering their regional characteristics including macro as well as micro information. The methodology to evaluate potential seismic risk of urban cities consists of Step-(1) through Step-(5) as follows.

[*Step-(1): Assembling of statistical related to regional characteristics*]: Statistical and field survey were made to investigate and assemble the informative data of regional characteristic in each city related to potential seismic risk shown in the last column of **Table 1(a)** and **(b)** (Detailed data).

[*Step-(2): Calculation of statistical data values through principal component analysis*]: In this step, to calculate the statistical values, i.e. *principal component, eigen value, proportion, accumulated proportion, factor loading*, relating to potential seismic risk, i.e. R_S, R_B, R_F, R_{RES}, C_{RES}, C_A and C_R, *principal component analysis* [Okuno et al. (1971)] was carried out using data obtained in step-(1).

[*Step-(3): Categorizing principal component and determination of factor score*]: On the basis of the statistical values calculated in Step-(2), categorizing *principal components* are first carried out in this step. Then *factor score* (FS in shown **Figure. 2**) of each city is calculated from the categorized *principal components. Principal components* which have *eigen value, accumulated proportion, factor loading* exceeding 1.0, 80 %, 0.8, respectively, are classified into the same category.

[*Step-(4): Clustering of each city*]: Each city is then clustered with Eq. (1) and *factor score* calculated in Step-(3). A city with the highest *factor score* in each category is classified as *CL (class value)*=10, and a city with the lowest *factor score* in each category is classified as *CL (class value)*=0, respectively.

$$CL(t,n) = \{FS_t(n) - Min[FS_t(n)]\} \times 10 / MFS_t(n) \quad (1)$$

where, $CL(t,n)$ *:* Class value *of each city [0* $\leq CL(t,n) \leq$ *10]*

$FS_t(n)$ *:* Factor score *of each city in each category (* t *)*

$MFS_t(n) : Max\{FS_t(n) - Min[FS_t(n)]\}$, t : category, n : City ID

[*Step-(5): Scoring and grouping of each city*]: Scores of each city are calculated with Eq. (2).

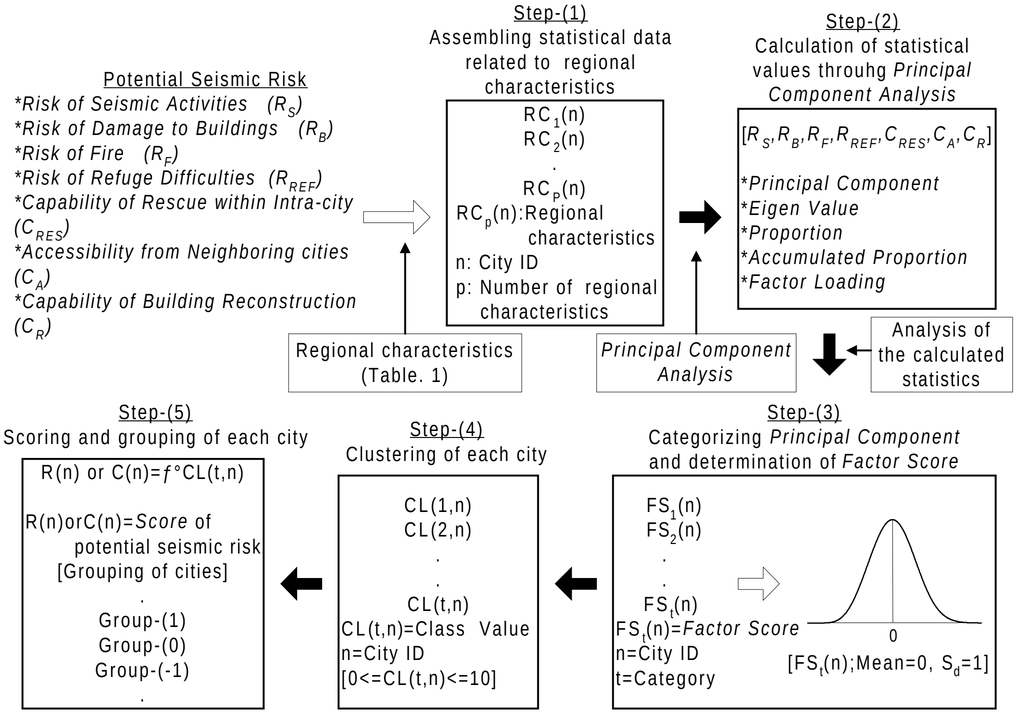


Figure 2: Procedures of potential seismic risk assessment of urban cities

$$R(n) \quad or \quad C(n) = \sum CL(t,n) \tag{2}$$

where, $R(n)$, $C(n)$: *Score* of potential seismic risk, i.e. R_S, R_B, R_F, R_{RES}, C_{RES}, C_A and C_R

$$0 \le R(n) or C(n) \le 10 \quad (t = 1)$$
$$0 \le R(n) or C(n) \le 20 \quad (t = 2)$$
$$\ldots\ldots\ldots$$
$$0 \le R(n) or C(n) \le 10T \quad (t = T)$$

t : category, T □Number of total category, $CL(t,n)$ = *Class value* of each city shown in *Step-(4)*

Table 2 shows the procedure of the grouping of cities. Cities of which score of potential seismic risk of *R* or *C* is in the range as Eq. (3) are classified into *mean group*, g*roup-(0)*, in this paper.

$$M - 0.3S_d < R(n) \quad or \quad C(n) \le M + 0.3S_d \tag{3}$$

M and S_d represent the *mean value* and *standard deviation* of score of potential seismic risk of whole investigated cities. When a city has the potential seismic risk of *R* or *C* higher or lower than *mean group*, it is classified as shown in **Table 2**.

ESTIMATION OF POTENTIAL SEISMIC RISK

Investigated Cities and Wards:

Figure 3 shows the location of the investigated cities and wards. Twenty nine urban cities and 141 wards in Japan including Kobe districts damaged by 1995 Hyogoken-Nambu Earthquake are investigated in this paper.

Relationships between Estimated Potential Seismic Risk and Damaged Cities:

To clarify the accuracy of the estimated potential seismic risk in this study, the relationships between the estimated potential seismic risk and the damage observed in Kobe city, Nishinomiya, Ashiya and Takarazuka city (Maximum seismic intensityVII in JMA scale) during the 1995 Hyogoken-Nambu Earthquake were investigated. The investigated potential seismic risks were (1) *Risk of Damage to Buildings* R_B, (2) *Risk of Fire* R_F and (3) *Capability of Building Reconstruction* C_R, in which results of R_B and R_F for Kobe, Nshinomiya, Ashiya and Takarazuka city were compared with the observed damage while those of C_R for only Kobe city

Table 2: Procedure of grouping

Potential seismic risk	Group	Range of score of potential seismic risk [R(n) or C(n)]
Higher ↑	…..	…..
	Group-(3)	$M+1.5S_d < R(n)$ or $C(n) \leqq M+2.1S_d$
	Group-(2)	$M+0.9S_d < R(n)$ or $C(n) \leqq M+1.5S_d$
	Group-(1)	$M+0.3S_d < R(n)$ or $C(n) \leqq M+0.9S_d$
Mean Group	Group-(0)	$M-0.3S_d < R(n)$ or $C(n) \leqq M+0.3S_d$
↓ Lower	Group-(-1)	$M-0.9S_d < R(n)$ or $C(n) \leqq M-0.3S_d$
	Group-(-2)	$M-1.5S_d < R(n)$ or $C(n) \leqq M-0.9S_d$
	Group-(-3)	$M-2.1S_d < R(n)$ or $C(n) \leqq M-1.5S_d$
	…..	…..

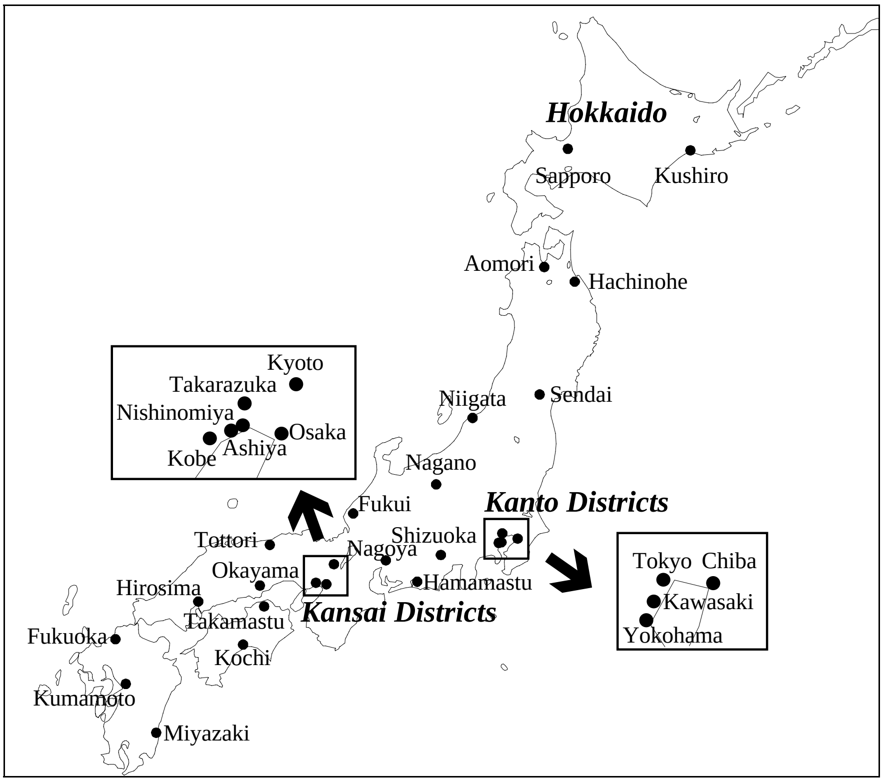


Figure 3: Location of investigated cities and wards

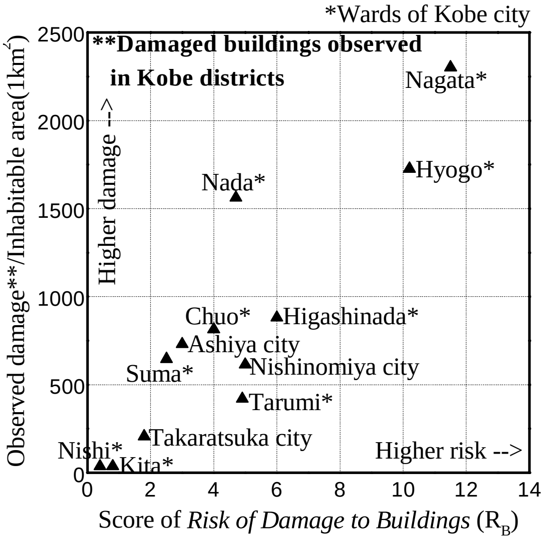
were compared with the observed damage. The relationships between the damage to buildings and the estimated potential seismic risk; (1) R_B, (2) R_F and (3) C_R were shown in **Figure 4(a)** through **(c)**. These Figures show that the wards and cities with heavier damage by the 1995 Hyogoken-Nambu Earthquake show higher potential seismic risk and the methodology proposed in this study compares well with the observed evidence.

Results of Risk Estimation for Typical Cities in Japan:

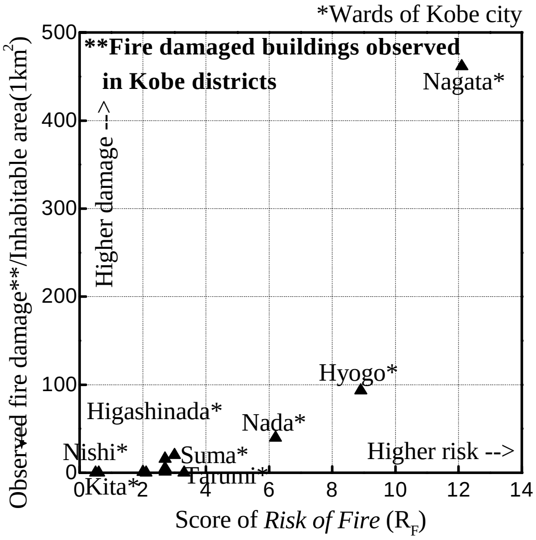
Potential seismic risks of typical cities or wards in Japan shown in **Figure 3** were estimated with the proposed methodology. Among the estimated potential seismic risk, *Risk of Damage to Buildings* R_B, *Risk of Fire* R_F, *Capability of Rescue within Intra-City* C_{RES} and *Capability of Building Reconstruction* C_R in Hokkaido, Kanto and Kansai districts are shown in **Figure 5(a)** through **(d)**, respectively. the following findings can be obtained.

(1) From the comparison of the estimated potential seismic risk among cities, it is possible to select a city or a group of cities where urgent earthquake preparedness measures are needed.

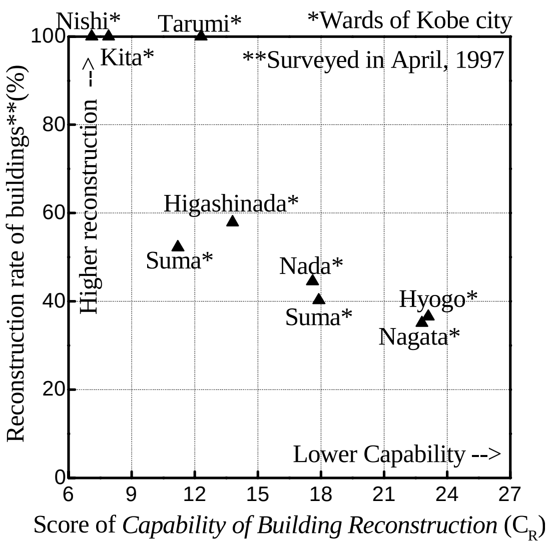
(2) Bearing the observed damage due to the 1995 Hyogoken-Nambu Earthquake in mind, it is possible to understand the estimated potential seismic risk level in each city through a comparison with the estimated results in Kobe city.
(3) It is possible to understand a disaster pattern and to identify the highest risk expected in the city. This information can be utilized to identify urgently required earthquake preparedness measures with highest priority in each city.



(a) Relationships between **R_B** ***and damage to buildings***



(b) Relationships between **R_F** ***and fire damage to buildings***



(c) ***Relationships between*** **C_R** ***and reconstruction ratio of buildings***

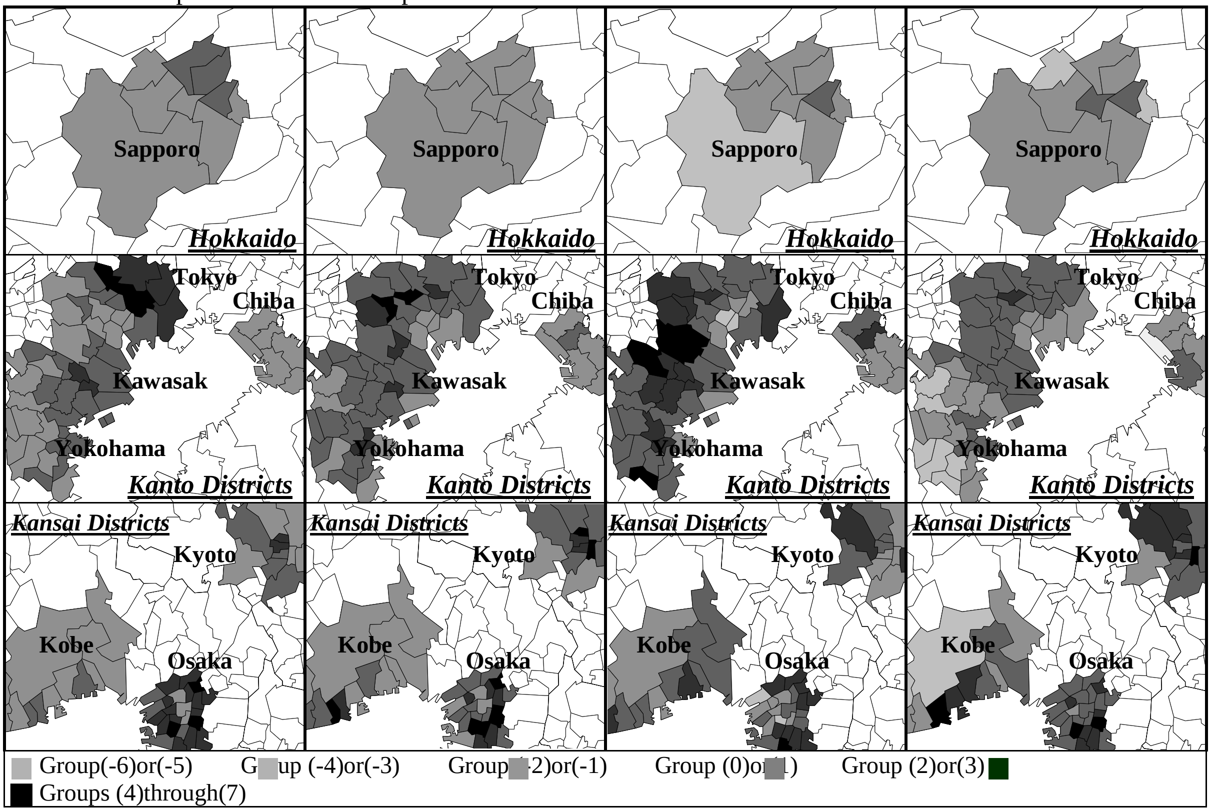
Figure 4: Relationships between **R_B , R_F** ***and*** **C_R** ***and damage observed in Kobe districts damaged by 1995 Hyogoken-Nambu Earthquak***

CONCLUDING REMARKS

In this study, the methodology to estimate potential seismic risk in urban cities based on their regional characteristics including *Macro Information* as well as *Micro Information* was proposed. The methodology was applied to typical urban cities in Japan, and its applicability to assess the potential seismic risk was also discussed. The results can be summarized as follows.

(1) The proposed methodology can be a useful strategy to identify cities of which potential seismic risk are high, and to recommend urgently required earthquake preparedness measures.

(2) The estimated potential seismic risk with the proposed methodology compares well with the damage observed in Kobe districts.
(3) For the future earthquake preparedness measures, it is recommended to select cities where urgent earthquake preparedness measures are required, and to classify and identify items of their regional characteristics which should be improved to reduce the potential seismic risk.



(a) ***Risk of Bamage to Buildings (R_B)*** **(b)** ***Risk of Fire (R_F)*** **(c)** ***Capability of Rescue within Intra-City (C_{RES})*** **(d)** ***Capability of Building Reconstruction (C_R)***

Figure 5: Estimated potential seismic risk

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