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ASSESSING POTENTIAL SEISMIC RISK AND EARTHQUAKE DISASTER PATTERNS FOR JAPANESE CITIES ACCORDING TO THEIR REGIONAL CHARACTERISTICS

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ABSTRACT: This study sets out a methodology for estimating a city's potential seismic risk. This methodology, which considers all phases of an earthquake disaster, is based on regional characteristics that are derived from macro-information such as topography, climate, location of active faults, regional building types and their seismic capacity, experience of past earthquake disasters, inter-city traffic systems, and accessibility from neighboring cities, as well as from the micro-information presently used in current methodologies such as soil and building conditions, open areas, fire-resistant buildings, and building-to-land ratios. This methodology was applied to typical cities in Japan. The degree to which this methodology was able to accurately assess the potential seismic risk and earthquake disaster patterns for these cities are also discussed herein.

Key Words: potential seismic risk, earthquake disaster patterns, regional characteristics, micro-information, macro-information, earthquake preparedness measures

INTRODUCTION

Japan has experienced many large earthquakes, including the 1923 Great Kanto Earthquake. Various schemes for assessing seismic risk have been developed and applied to numerous cities, especially after the 1995 Hyogoken-Nambu Earthquake. Existing Japanese seismic risk assessment methodologies, in the main, consider regional characteristics such as soil conditions, building conditions, open areas, fire-resistant buildings, and building-to-land ratios from a micro-point of view. When a very large area is assessed, such as a large metropolitan area, the area is subdivided in order to estimate quantitatively the post-earthquake damage to the built-up environment immediately after an event. However, the 1995 Hyogoken-Nambu Earthquake revealed that the methodologies in use were not adequate for the task of estimating real seismic risk. The event also revealed that an earthquake disaster in a city involves more than just the phase of post-earthquake damage to the built-up environment immediately after the event; there are subsequent phases of damage that are dependent on human activities, such as, for example, inter- and intra-city rescue activities in the emergency response period and reconstruction in the mid- to long-term period following the earthquake. These phases are affected by regional characteristics derived from macro-information, such as topography, climate, location of active faults, regional building types and their seismic capacity, experience of past earthquake disasters, the background history of urban development, inter-city traffic systems, and accessibility from neighboring cities, as well as from the micro-information presently used in current methodologies.

The phases that are dependent on human activities and the interrelationship of these human activities to regional characteristics have not been fully considered in the current methodologies primarily because these considerations go beyond the micro-perspective utilized in these methodologies. Therefore, in order to assess a city's seismic risk, and to utilize this information for the rational implementation of earthquake preparedness measures in the future, it is necessary to develop a new methodology that considers all damage phases of an earthquake disaster. These phases are related to time-dependent patterns that are based on regional characteristics derived from both macro- and micro-information.

This study proposes a methodology for qualitatively estimating a city's potential seismic risk. This methodology, which considers all phases of an earthquake disaster, is based on a city's regional characteristics that are derived from both macro- and micro-information. Typical cities in Japan were selected and their potential seismic risk was estimated according the above methodology. In order to verify the applicability of the proposed methodology, the relationships between the estimated potential seismic risk and the damage caused in districts of Kobe during the 1995 Hyogoken-Nambu Earthquake are investigated. Furthermore, this study sets out an earthquake disaster pattern for the cities investigated here in order to provide basic information useful for the implementation of countermeasures against future earthquakes.

In this paper, regional characteristics that are common to several cities, and sometimes to prefectures, such as wind maps, active faults maps, seismic risk maps, and snow maps, are referred to as *macro-information*, while regional characteristics that are localized to some part of a city, such as the soft soil ratio, number of wooden buildings, and number of open spaces, are referred to as *micro-information*.

CRITERIA FOR EVALUATING POTENTIAL SEISMIC RISK AND THE CLASSIFICATION OF RELATED REGIONAL CHARACTERISTICS

Fig. 1 shows the relationships between an earthquake disaster and interactive effects, based on phenomena related to typical damage caused by earthquakes in Japan. As shown in Fig. 1, an earthquake disaster involves not only the immediate post-earthquake phase of damage to the built-up environment, but also time-dependent phases of damage based on human activities. Especially in the 1995 Hyogoken-Nambu Earthquake, some damage phases of earthquake disaster such as difficulties with inter- and intra-city rescue activities in the emergency response period, and mid- to long-term reconstruction phases are pointed out (AIJ 1995, NBPC 1995, and AIJ 1997).

An earthquake disaster is a complex event, involving many phenomena, as shown in Fig. 1. In this study, in order to simplify the subsequent discussion, we derive typical phenomena that are related to earthquake disasters. These are shown in italics in Fig. 1, and are integrated from various phenomena within each time-dependent pattern. Based on these derived phenomena, we determined criteria to evaluate the potential seismic risk to cities. These are underlined in the following four phases.

Phase 1, Before an earthquake: *Risk of Seismic Activity* (R_{SA})

Phase 2, Immediately after an earthquake: *Risk of Damage to Buildings* (R_{DB}), *Risk of Fire* (R_F), and *Risk of Refuge Difficulties* (R_{RD})

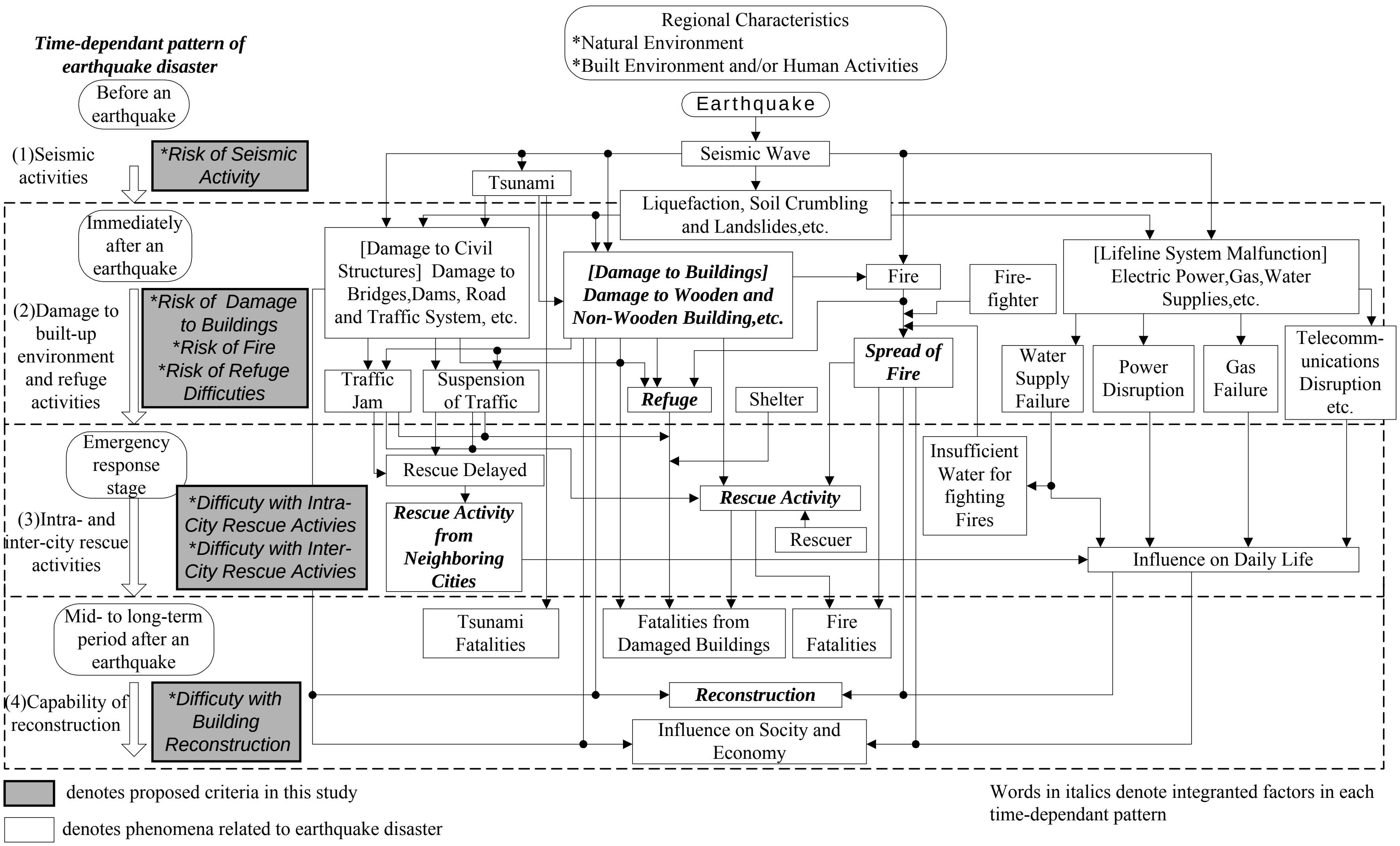


Fig. 1 Relationship between an earthquake disaster and interactive effects based on typical earthquakes experienced in Japan.

Phase 3, Emergency response stage: *Difficulty with Intra-City Rescue Activities* (D_{IAR}) and *Difficulty with Inter-City Rescue Activities* (D_{IRR})

Phase 4, Mid- to long-term period after an earthquake: *Difficulty with Building Reconstruction* (D_{BR})

Table 1 (a)-(d) shows the regional characteristics related to the potential seismic risk (R_{SA}, R_{DB}, R_F, R_{RD}, D_{IAR}, D_{IRR}, and D_{BR}) of cities in Phases 1 through 4 described above. Each characteristic that appears in Table 1 was derived from macro- information, which refers to regional characteristics that are common to several cities or even to several prefectures, and micro-information, which includes features localized to some part of a city. These characteristics were derived from records of past earthquake disasters in Japan (Usami 1996), including the 1891 Nobi, 1923 Kanto, 1968 Tokachi-oki, 1978 Miyakiken-oki, and 1995 Hyogoken-Nambu earthquakes. As shown in Table 1, the potential seismic risk is closely related to various regional characteristics derived from both macro-information and micro-information.

METHODOLOGY FOR ASSESSING POTENTIAL SEISMIC RISK

Fig. 2 shows the procedures used to assess potential seismic risk. These consider regional characteristics derived from macro- and micro-information. The methodology used to evaluate the potential seismic risk to a city consists of Steps 1 through 5, as follows:

Step 1, *Assemble statistical data related to regional characteristics:* Statistical and field surveys are used to obtain informative data on regional characteristics for each city that are related to the potential seismic risk, as shown in the last column of Table 1 (Detailed data).

Step 2, *Use principal component analysis to calculate statistical values*: In this step, in order to calculate the statistical values (*i.e.*, principal component, eigenvalue, proportion, accumulated proportion, and factor loading) related to the potential seismic risk (*i.e.*, R_{SA}, R_{DB}, R_F, R_{RD}, D_{IAR}, D_{IRR}, and D_{BR}), principal component analysis (Okuno 1971) is carried out using the data obtained in Step 1.

Step 3, *Categorize principal components and determine factor scores*: Using the statistical values calculated in Step 2, categorize the principal components. Then the factor score (*FS* in Fig. 2) of each city is calculated from the principal components. Principal components with an eigenvalue, accumulated proportion, and factor loading exceeding 1.0, 80%, and 0.8, respectively, are classified together.

Step 4, *Cluster the cities*: The cities are then clustered using Eq. (1) and the factor score calculated in Step 3. The city with the highest factor score in each category is classified as *CL* (class value)=10, and the city with the lowest factor score in each category is classified as *CL* (class value)=0.

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

where $CL(t,n)$ is the class value of each city $[0 \leq CL(t,n) \leq 10]$, $FS_t(n)$ is the factor score of each city in each category (t), $MFS_t(n)$ is calculated using $Max\{FS_t(n) - Min[FS_t(n)]\}$, t is the category number, and n is the city ID.

Step 5, *Score and group each city*: The scores of each city are calculated using Eq. (2).

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

Table 1 Regional characteristics related to the potential seismic risk of urban cities

(a) Phase 1: *Risk of Seismic Activity* (R_{SA})

Criterion	Regional characteristics summarized and classified: Item	Regional characteristics summarized and classified: Sub-Item [Statistical ref.]	Detailed data
R_{SA}	History of seismic hazards*	Frequency and location of damaging past earthquakes centered on off-coastal and inland areas of Japan [Usami 1996]	[RC_{SA1}]: Number of past^{+} earthquakes^{++} centered off the coast of Japan, [RC_{SA2}]: Number of past^{+} earthquakes^{++} centered on Japan mainland, [RC_{SA3}]: Number of active faults within 30 km of the city center $^{+}$ 590 through 1995 $^{++}$ Intensity V or greater on the JMA scale
	Active faults*	Number of active faults [RGAFJ 1995, Matsuda 1981]	

* Regional characteristics related to macro-information.

(b) Phase 2: *Risk of Damage to Buildings* (R_{DB}), *Risk of Fire* (R_F), and *Risk of Refuge Difficulties* (R_{RD})

Criteria	Regional characteristics summarized and classified: Item	Regional characteristics summarized and classified: Sub-Item [Statistical ref.]	Detailed data
R_{DB}	Soil conditions	Soft soil (alluvium, delta, reclaimed land, tideland, fan) ratio [GSI 1992]	[RC_{DB1}]: Number of wooden buildings with tiled roofs, constructed before 1981, [RC_{DB2}]: Number of wooden buildings without tiled roofs, built on soft soil, constructed before 1981, [RC_{DB3}]: Number of non-wooden buildings built on soft soil, constructed before 1971, [RC_{DB4}]: Number of wooden buildings built on soil likely to experience liquefaction and land slides etc., constructed after 1981, [RC_{DB5}]: Number of non-wooden buildings built on soil related to liquefaction and land slides etc., constructed after 1971
		Soil ratio likely to cause liquefaction and land slides, etc. (delta, filled up land, reclaimed land, tideland, developed land, seashore sand, natural levee, fan, swamp) [GSI 1992]	
	Building conditions	Wooden buildings constructed before 1981 [SBSCJ 1993]	
		Non-wooden buildings constructed before 1971 [SBSCJ 1993]	
	Regional building types*	Roof types, amount of walls, foundation type [Based on a field survey by the authors]	
	History of urban development*	Relationship between past and present land conditions [Yamakuchi 1980]	
R_F	Fire-spread factors	Wooden buildings [SBSCJ 1993]	[RC_{F1}]: Number of wooden buildings (with building coverage more than 60% and abutting on a road less than 6 m wide) causing fire to spread, [RC_{F2}]: Average wind speed during the past 30 years, [RC_{F3}]: Ratio of wooden buildings causing fire spread to fire-resistant buildings, [RC_{F4}]: Ratio of wooden buildings causing fire to spread to buildings abutting on a road more than 6-m wide, [RC_{F5}]: Ratio of wooden buildings causing fire to spread to a city park, [RC_{F6}]: Ratio of wooden buildings causing fire spread to a fire station
		Buildings with building coverage more than 60% [SBSCJ 1993]	
		Buildings abutting on a road less than 6-m wide [SBSCJ 1993]	
		Wind speed* [JMA 1998]	
	Fire-preventi on factors	Buildings abutting on a road more than 6-m wide [SBSCJ 1993]	
		Fire-resistant buildings [SBSCJ 1993]	
		Open spaces [SBSCJ 1995]	
		Fire fighting capacity [FDAJ 1995]	
R_{RD}	Refuge road conditions	Buildings abutting on a road less than 6-m wide [SBSCJ 1993]	[RC_{RD1}]: Number of buildings abutting on a road less than 6-m wide, [RC_{RD2}]: Ratio of population per city park, [RC_{RD3}]: Ratio of population per school building
	Shelter facilities	Parks, school buildings, and other facilities [SBSCJ 1995]	

* Regional characteristics related to macro-information (other characteristics are related to micro-information).

(c) Phase 3: *Difficulty with Intra-City Rescue Activities* (D_{IAR}) and *Difficulty with Inter-City Rescue Activities* (D_{IRR})

Criteria	Regional characteristics summarized and classified		Detailed data
	Item	Sub-Item [Statistical ref.]	
D_{IAR}	Capability of rescue	Buildings abutting on a road less than 6-m wide [SBSCJ 1993]	[RC_{IAR1}]: Number of buildings abutting on a road less than 6-m wide, [RC_{IAR2}]: Ratio of population per fire fighter, [RC_{IAR3}]: Ratio of population per hospital, [RC_{IAR4}]: Ratio of population per park, [RC_{IAR5}]: Ratio of population per school
		Rescuer [FDAJ 1995]	
		Medical facilities [SBSCJ 1995]	
	Rescue center	Parks, school buildings, and other facilities [SBSCJ 1995]	
D_{IRR}	Scale of Supporting city*	Population of supporting city [SBSCJ 1995]	[RC_{IRR1}]: Population of support city, [RC_{IRR2}]: Number of land traffic systems, [RC_{IRR3}]: The distance from city center to the nearest seaport, [RC_{IRR4}]: The distance from city center to the nearest airport
	Inter-city traffic systems*	Land, sea, and air traffic systems [SBSCJ 1995, PCTM 1997]	

* Regional characteristics related to macro-information (others are related to micro-information).

(d) Phase 4: *Difficulty with Building Reconstruction* (D_{BR})

Criterion	Regional characteristics summarized and classified		Detailed data
	Item	Sub-Item [Statistical ref.]	
D_{BR}	Economic conditions and houses for the aged*	Low income household [SBSCJ 1993]	[RC_{BR1}]: Ratio of households with an annual income of less than 3 million yen [RC_{BR2}]: Ratio of households for the aged [RC_{BR3}]: Ratio of rented houses [RC_{BR4}]: Ratio of owned houses [RC_{BR5}]: Ratio of wooden buildings constructed before 1971 [RC_{BR6}]: Ratio of buildings with a site area of less than $50m^2$ [RC_{BR7}]: Ratio of buildings abutting on a road less than 4-m wide
		Houses for the aged [SBSCJ 1993]	
	Owned and rented houses*	Owned houses [SBSCJ 1993]	
		Rented houses [SBSCJ 1993]	
	City area conditions*	Buildings with a site area less than 50 m^2 [SBSCJ 1993]	
		Buildings abutting on a road less than 4-m wide [SBSCJ 1993]	
		Wooden buildings constructed before 1971 [SBSCJ 1993]	

* Regional characteristics related to micro-information.

where $R(n)$ or $D(n)$ is the score of potential seismic risk, *i.e.*, R_{SA}, R_{DB}, R_F, R_{RD}, D_{IAR}, D_{IRR}, and D_{BR}, which range as follows:

$$0 \leq R(n) \text{ or } D(n) \leq 10 \quad (t{=}1)$$
$$0 \leq R(n) \text{ or } D(n) \leq 20 \quad (t{=}2)$$
$$\ldots$$
$$0 \leq R(n) \text{ or } D(n) \leq 10T \quad (t{=}T)$$

$CL(t,n)$ is the class value of each city in Step 4, t is the category number, and T is the total number of categories.

Table 2 shows the procedure used to group cities. In this study, cities with a potential seismic risk score of R or D in the range of Eq. (3) are classified in the mean group, or group-(0):

$$M - 0.3S_d < R(n) \text{ or } D(n) \leq M + 0.3S_d \quad (3)$$

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

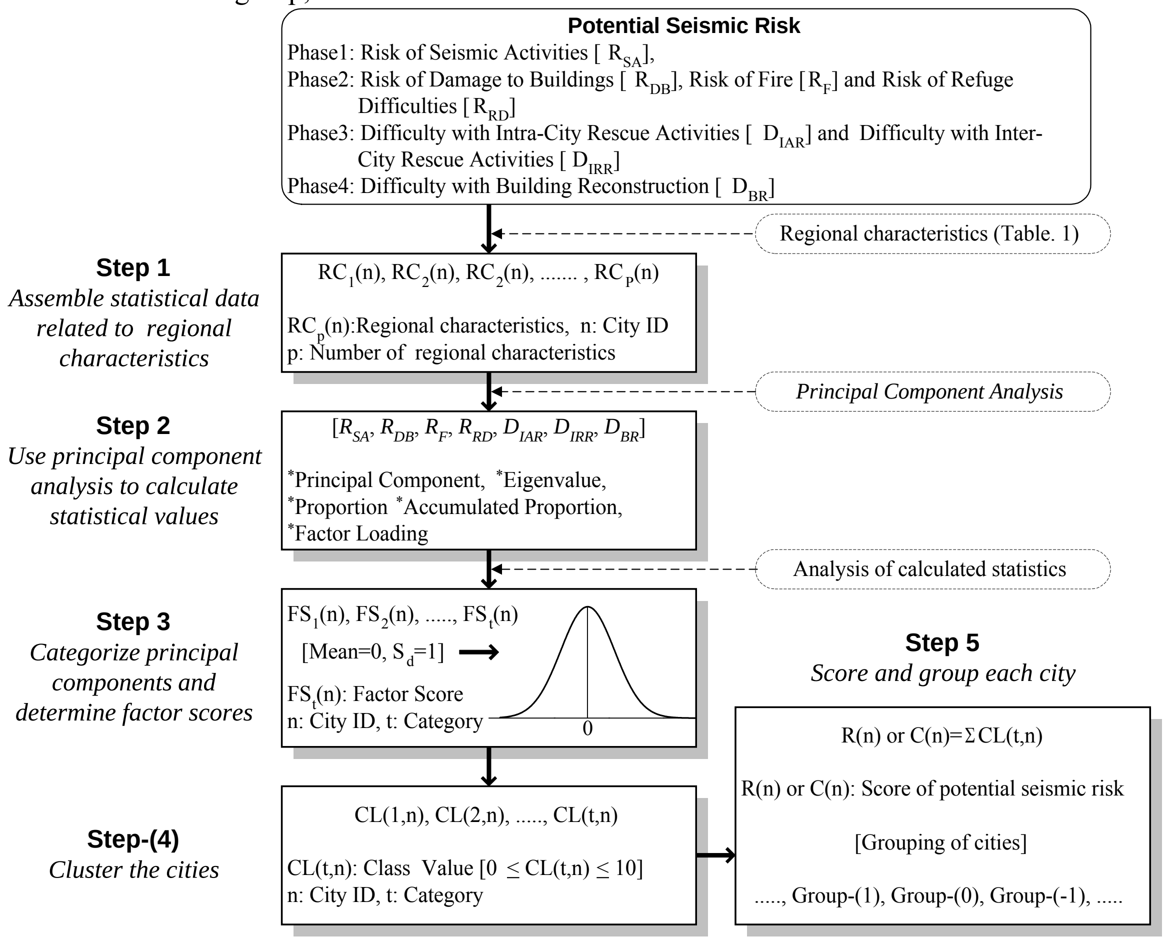


Fig. 2 Procedures of potential seismic risk assessment of urban cities

Table 2 Grouping procedure

Potential seismic risk	Group	Range of scores for potential seismic risk [$R(n)$ or $D(n)$]
Higher	…	…
	Group-(3)	$M + 1.5S_d < R(n)$ or $C(n) \leq M + 2.1S_d$
	Group-(2)	$M + 0.9S_d < R(n)$ or $C(n) \leq M + 1.5S_d$
	Group-(1)	$M + 0.3S_d < R(n)$ or $C(n) \leq M + 0.9S_d$
Mean Group	*Group*-(0)	$M - 0.3S_d < R(n)$ or $C(n) \leq M + 0.3S_d$
	Group-(-1)	$M - 0.9S_d < R(n)$ or $C(n) \leq M - 0.3S_d$
	Group-(-2)	$M - 1.5S_d < R(n)$ or $C(n) \leq M - 0.9S_d$
	Group-(-3)	$M - 2.1S_d < R(n)$ or $C(n) \leq M - 1.5S_d$
Lower	…	…

ESTIMATING POTENTIAL SEISMIC RISK

Cities and Wards Investigated

Twenty-nine typical cities in Japan, including the Kobe districts damaged during the 1995 Hyogoken-Nambu Earthquake, were selected in this study as shown in Fig. 3. Among the selected cities, ward levels for twelve Ordinance-Designated-Cities (i.e. 141 wards) and city levels for the others (i.e. 17 cities) as shown in figure were investigated for estimating their potential seismic risks, respectively.

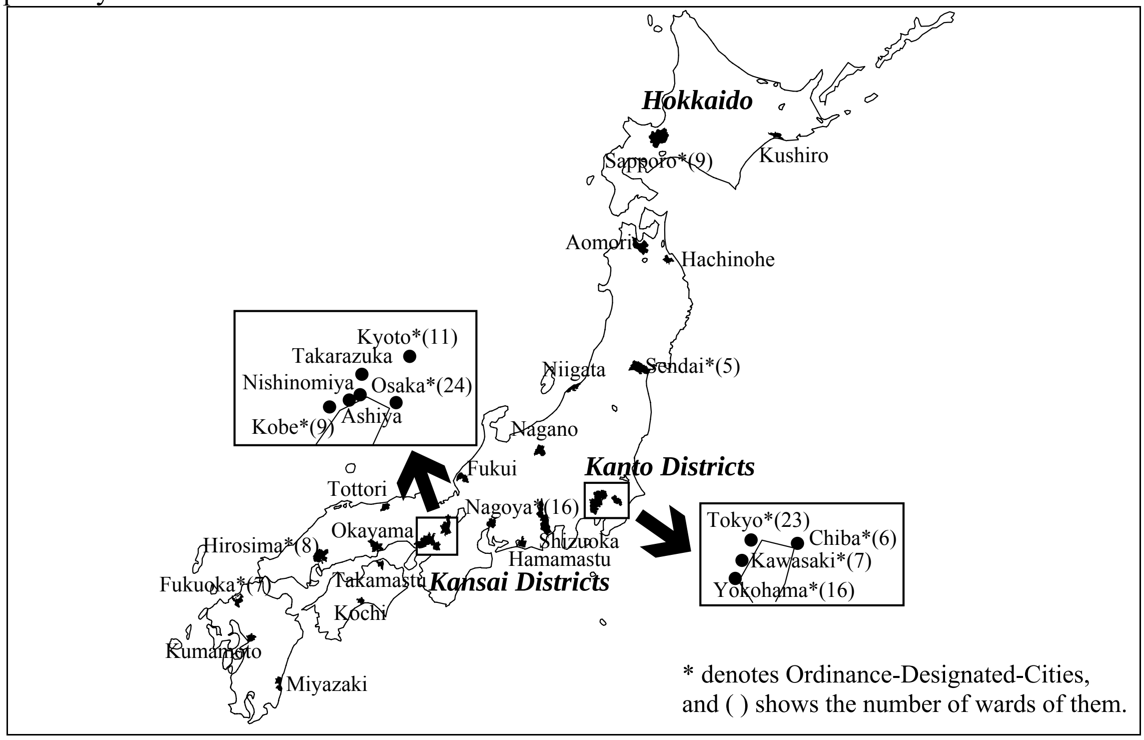


Fig. 3 Location of the Japanese cities and wards studied

Relationship between Estimated Potential Seismic Risk and Damaged Cities

In order to evaluate the accuracy of the estimated potential seismic risk in this study, the relationship between the estimated potential seismic risk and the actual damage observed in Kobe, Nishinomiya, Ashiya, and Takarazuka (Maximum seismic intensity VII on the JMA scale) during the 1995 Hyogoken-Nambu Earthquake (AIJ 1995) was investigated. The potential seismic risks studied were (1) *Risk of Damage to Buildings* (R_{DB}), (2) *Risk of Fire* (R_F), and (3) *Difficulty with Building Reconstruction* (D_{BR}); the results for R_{DB} and R_F for Kobe, Nishinomiya, Ashiya, and Takarazuka were compared with the observed damage (Kobe City 1997 and JNLA 1996), and the D_{BR} for Kobe was compared with the observed reconstruction ratio (AIJ 1997).

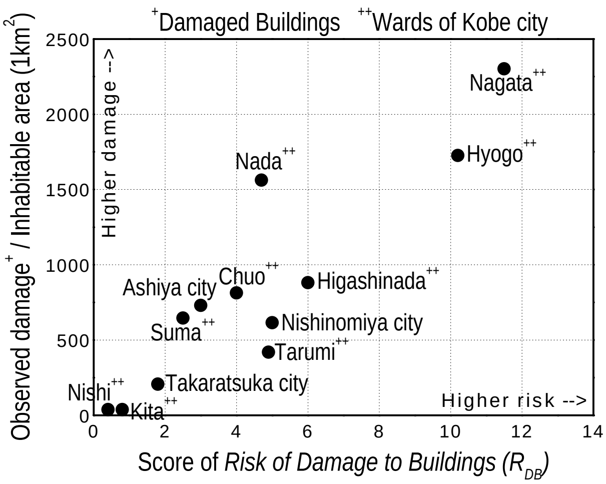
The relationships between the damage to buildings, or the reconstruction ratio, and the estimated potential seismic risk, (1) R_{DB}, (2) R_F, and (3) D_{BR}, are shown in Fig. 4(a)-(c), respectively. These figures show that the wards and cities in which the 1995 Hyogoken-Nambu Earthquake caused greater damage or a lower reconstruction ratio, have a higher potential seismic risk. The methodology proposed in this study compares reasonably well with the observed evidence.

Results of Risk Estimation for Typical Cities in Japan

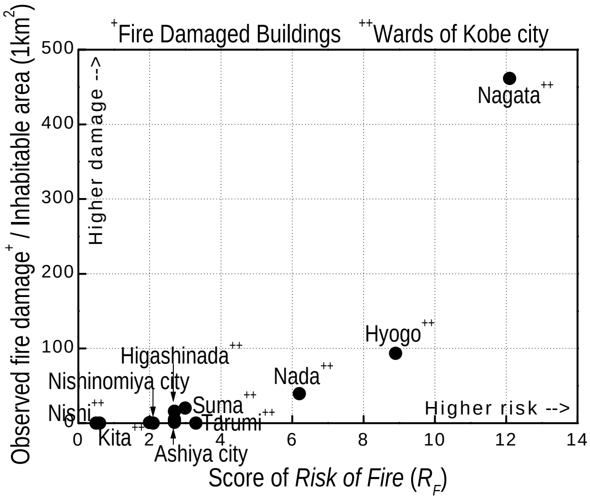
The potential seismic risk of the Japanese cities and wards shown in Fig. 3 was estimated using the proposed methodology. Tables 3(a)-(f) show the estimated potential seismic risk, *i.e.*, R_{SA}, R_{DB}, R_F, R_{RD}, D_{IAR}, D_{IRR}, and D_{BR} in Tables 3(a)-(f) respectively, of the cities and wards studied in Phases 1 to 4, *i.e.*, twenty-nine cities and 141 wards in Japan. As shown in Table 3(a), the detailed data related to R_{SA} and D_{IRR},, shown in Table 1, were neglected when clustering wards to simplify the analyses, since these data were not available for every ward. The following results were obtained:

1. Nishinari Ward, Osaka, was classified as belonging to group-(6) with respect to *Risk of Damage to*

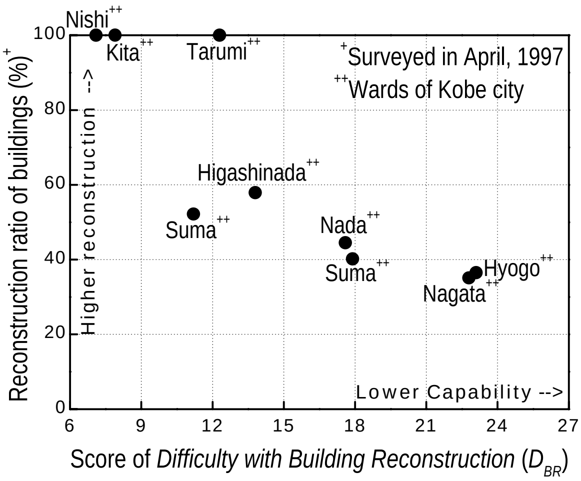
Buildings, to group-(7) with respect to *Risk of Fire*, and to group-(6) with respect to *Difficulty with Building Reconstruction*; it had the highest potential seismic risk of all the cities investigated.



(a) Relationship between R_{DB} and damage to buildings (Kobe City 1997 and JNLA 1996)



(b) Relationship between R_F and fire damage to buildings (Kobe City 1997 and JNLA 1996)



(c) Relationship between D_{BR} and the reconstruction ratio of buildings (AIJ 1997)

Fig. 4 Relationships between the estimated potential seismic risk (R_{DB}, R_F, and D_{BR}) and damage observed in districts of Kobe damaged in the 1995 Hyogoken-Nambu Earthquake

2. Chiyoda Ward, Tokyo, was classified as belonging to group-(-2) with respect to *Risk of Damage to Buildings*, to group-(-2) with respect to *Risk of Fire*, to group-(-4) with respect to *Risk of Refuge Difficulties*, and to group-(-4) with respect to *Difficulties with Intra-City Rescue Activities*; it was identified as having the lowest risk of all the cities investigated.
3. Nagata and Hyogo Wards, in Kobe, were severely damaged during the 1995 Hyogoken-Nambu Earthquake; these wards had the highest risk in the Kobe area, and were identified as having a relatively high potential seismic risk among the cities studied.
4. Kita and Nishi Wards, in Kobe, were slightly damaged by the 1995 Hyogoken-Nambu Earthquake and had the lowest risk in the Kobe area; these wards had a relatively low potential seismic risk among the cities investigated.
5. By considering the observed damage following the 1995 Hyogoken-Nambu Earthquake, it is possible to evaluate the accuracy of the estimated potential seismic risk level for each city by comparison with the estimated results for Kobe.

Table 3 The estimated potential seismic risk

(a) *Risk of Seismic Activity* (R_{SA}) and *Difficulty with Inter-City Rescue Activities* (D_{IRR})

Group	Cities	
	Risk of Seismic Activity	Difficulty with Inter-City Rescue Activities
Group-(4)	Kyoto	Nagano
Group-(3)	Hachinohe, Sendai, Osaka	Kyoto
Group-(2)	Tokyo 23 ward, Miyazaki	Kushiro
Group-(1)	Kushiro, Nagano	Sapporo, Aomori, Sendai, Shizuoka, Tottori, Kochi, Miyazaki
Group-(0) Mean group	Yokohama, Fukui, Shizuoka, Hamamatsu, Nagoya, Kumamoto	Hachinohe, Niigata, Fukui, Hamamatsu, **Kobe***, Okayama, Hiroshima, Takamatsu, Fukuoka, Kumamoto
Group-(-1)	Aomori, Kawasaki, Niigata, **Kobe***, **Nishinomiya***, **Ashiya***, **Takarazuka***, Hiroshima, Takamatsu, Kochi	Chiba, **Ashiya***, **Takarazuka***
Group-(-2)	Chiba, Tottori, Okayama, Fukui	Yokohama, Nagoya, **Nishinomiya***
Group-(-3)	Sapporo	Tokyo 23 wards, Kawasaki, Osaka

* Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

(b) *Risk of Damage to Buildings* (R_{DB})

Group	Cities or Wards
Group-(6)	Osaka (Ikuno, Nishinari)
Group-(5)	Tokyo (Taito, Kita, Arakawa)
Group-(4)	Tokyo Sumida, Osaka Asahi
Group-(3)	Tokyo (Adachi, Katsushika), Kawasaki Nakahara, Osaka (Minato, Higashinari, Joto, Higashisumiyoshi, Yodogawa)
Group-(2)	Tokyo Edogawa, Kawasaki Saiwai, Kyoto (Kamigyo, Nakagyo), Osaka (Miyakojima, Fukushima, Nishi, Taisho, Naniwa, Higashiyodogawa, Sumiyoshi, Tsurumi, Hirano), Hiroshima Naka, Fukuoka Chuo
Group-(1)	Sapporo (Kita, Higashi, Shiroishi), Tokyo (Shinagawa, Ota), Yokohama (Nishi, Minami), Kawasaki Takatsu, Nagoya (Kita, Nishi, Nakamura), Kyoto Shimogyo, Osaka Abeno, **Kobe** (**Hyogo**, **Nagata**)*, Fukuoka (Hakata, Minami, Jonan)
Group-(0) Mean group	Tokyo (Bunkyo, Koto, Meguro, Nakano, Toshima, Itabashi), Yokohama (Tsurumi, Kanagawa, Naka, Isogo, Kohoku, Sakae), Kawasaki (Kawasaki, Tama), Nagoya (Mizuho, Nakagawa, Minami), Kyoto (Minami, Sakyo, Fushimi), Osaka (Konohana, Nishiyodogawa, Suminoe), **Kobe Higashinada***, Hiroshima (Minami, Nishi)
Group-(-1)	Sapporo (Chuo, Nishi, Atsubetsu, Teine), Kushiro, Sendai (Miyagino, Wakabayashi), Chiba (Chuo, Hanamigawa, Inage, Mihama), Tokyo (Chuo, Minato, Shinjuku, Setagaya, Shibuya, Suginami, Nerima), Yokohama (Hodogaya, Kanazawa, Totsuka, Konan, Asahi, Midori, Seya, Izumi), Kawasaki (Miyamae, Asao), Niigata, Nagoya (Chikusa, Higashi, Showa, Atsuta, Minato, Moriyama, Midori, Meito, Tenpaku), Kyoto (Kita, Sakyo, Higashiyama, Yamashina, Nishikyo), Osaka (Tennoji, Kita, Chuo), **Kobe** (**Nada**, **Suma**, **Tarumi**, **Chuo**)*, **Nishinomiya***, **Ashiya***, **Takarazuka***, Okayama, Hiroshima (Higashi, Asaminami, Saeki), Takamatsu, Kochi, Fukuoka (Higashi, Nishi, Sawara), Kumamoto, Miyazaki
Group-(-2)	Sapporo (Toyohira, Minami), Aomori, Hachinohe, Sendai (Aoba, Taihaku, Izumi), Chiba (Wakaba, Midori), Tokyo Chiyoda, Fukui, Nagano, Shizuoka, Hamamatsu, Nagoya Naka, **Kobe** (**Kita**, **Nishi**) *, Tottori, Hiroshima (Asakita, Aki)

* Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

(c) *Risk of Fire* (R_F)

Group	Cities or Wards
Group-(7)	Osaka Nishinari
Group-(5)	Kyoto Higashiyama, Osaka (Higashinari, Ikuno)
Group-(4)	Tokyo (Nakano, Toshima), Kyoto Sakyo, Osaka (Asahi, Abeno,) **Kobe Nagata***
Group-(3)	Tokyo Arakawa, Kyoto (Nakagyo, Shimogyo), Osaka (Fukushima, Higashisumiyoshi), **Kobe Hyogo***
Group-(2)	Tokyo (Meguro, Suginami), Yokohama (Nishi, Minami), Kawasaki Saiwai, Osaka (Miyakojima, Joto, Sumiyoshi)
Group-(1)	Tokyo (Shinjuku, Bunkyo, Taito, Sumida, Shinagawa, Setagaya, Shibuya, Kita, Katsushika), Yokohama Seya, Kawasaki (Nakahara, Takatsu, Tama), Nagoya (Nakamura, Mizuho), Kyoto (Kita, Ukyo, Yamashina), Osaka (Minato, Taisho, Yodogawa, Tsurumi), **Kobe Nada***, Hiroshima Aki
Group-(0) Mean group	Chiba Inage, Tokyo (Ota, Itabashi, Nerima, Adachi, Edogawa), Yokohama (Tsurumi, Kanagawa, Hodogaya, Isogo, Kohoku, Konan, Asahi, Sakae, Izumi), Kawasaki (Miyamae, Asao), Nagoya (Higashi, Kita, Nishi, Showa, Atsuta, Minami), Kyoto (Sakyo, Minami), Osaka (Minami, Nishi, Tennoji, Naniwa, Nishiyodogawa, Higashiyodogawa, Hirano), **Kobe** (**Suma**, **Tarumi**) *, Hiroshima (Higashi, Minami), Fukuoka (Minami, Jonan)
Group-(-1)	Sapporo (Chuo, Shiroishi), Hachinohe, Sendai (Miyagino, Wakabayashi, Taihaku, Izumi), Chiba (Chuo, Hanamigawa, Wakaba, Midori), Tokyo (Chuo, Minato, Koto), Yokohama (Naka, Kanazawa, Totsuka, Midori), Kawasaki Kawasaki, Niigata, Nagoya (Chikusa, Naka, Nakagawa, Moriyama, Midori, Tenpaku), Kyoto (Fushimi, Nishikyo), Osaka (Konohana, Suminoe, Kita, Chuo), **Kobe** (**Higashinada**, **Chuo**) *, **Nishinomiya***, **Ashiya***, **Takarazuka***, Hiroshima (Naka, Nishi, Asaminami, Asakita, Saeki), Takamatsu, Kochi, Fukuoka (Higashi, Hakata, Chuo, Nishi, Sawara, Kumamoto
Group-(-2)	Sapporo (Kita, Higashi, Toyohira, Minami, Nishi, Atsubetsu, Teine), Kushiro, Aomori, Sendai Aoba, Chiba Mihama, Tokyo Chiyoda, Fukui, Nagano, Shizuoka, Hamamatsu, Nagoya (Minato, Meito), **Kobe** (**Kita**, **Nishi**) *, Tottori, Okayama, Miyazaki

* Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

(d) *Risk of Refuge Difficulties* (R_{RD})

Group	Cities or Wards
Group-(4)	Tokyo (Meguro, Setagaya, Nakano, Suginami, Toshima), Osaka Sumiyoshi
Group-(3)	Tokyo Arakawa, Kawasaki Takatsu, Osaka (Higashiyodogawa, Joto, Higashisumiyoshi, Nishinari, Chuo)
Group-(2)	Tokyo (Bunkyo, Shinagawa, Shibuya, Kita, Nerima, Katsushika, Edogawa), Kawasaki (Saiwai, Nakahara, Tama, Miyamae), Osaka (Miyakojima, Higashinari, Ikuno, Asahi, Abeno, Yodogawa, Tsurumi, Hirano), Fukuoka Jonan
Group-(1)	Tokyo (Shinjuku, Ota, Itabashi), Yokohama (Tsurumi, Minami, Hodogaya, Isogo, Kohoku, Konan, Seya), Nagoya (Kita, Showa, Mizuho), Kyoto (Kamigyo, Ukyo, Yamashina), Osaka Suminoe, **Kobe Hyogo***, **Nishinomiya***
Group-(0) Mean group	Sapporo (Shiroishi, Nishi), Chiba (Hanamigawa, Inage), Tokyo (Minato, Taito, Sumida, Koto, Adachi), Yokohama (Kanagawa, Nishi, Totsuka, Asahi, Izumi), Kawasaki Kawasaki, Nagoya (Chikusa, Nakamura, Atsuta, Nakagawa, Minato, Minami, Moriyama, Tenpaku), Kyoto (Kita, Nakagyo, Shimogyo, Nishikyo), Osaka (Fukushima, Konohana, Minato, Taisho), **Kobe** (**Higashinada**, **Nada**, **Tarumi**) *, **Ashiya***, Hiroshima (Higashi, Aki), Fukuoka (Higashi, Chuo, Minami), Kumamoto
Group-(-1)	Sapporo (Chuo, Higashi), Aomori, Sendai (Miyagino, Wakabayashi, Taihaku), Chiba Chuo, Yokohama (Kanazawa, Midori, Sakae), Kawasaki Asao, Nagano, Shizuoka, Hamamatsu, Nagoya (Nishi, Midori, Meito), Kyoto (Sakyo, Higashiyama, Minami, Fushimi), Osaka (Nishi, Kita), **Kobe** (**Nagata**, **Suma**, **Chuo**) *, **Takarazuka***, Okayama, Hiroshima (Naka, Minami, Nishi, Asaminami, Saeki), Takamatsu, Kochi, Fukuoka (Hakata, Sawara), Miyazaki
Group-(-2)	Sapporo (Kita, Toyohira, Atsubetsu, Teine), Kushiro, Hachinohe, Sendai (Aoba, Izumi), Chiba (Wakaba, Midori, Mihama), Yokohama Naka, Niigata, Nagoya (Higashi, Naka, Tennoji, Naniwa), Fukuoka Nishi
Group-(-3)	Sapporo Minami, Tokyo Chuo, Fukui, Osaka Nishiyodogawa, **Kobe** (**Kita**, **Nishi**) *, Tottori, Hiroshima Asakita
Group-(-4)	Tokyo Chiyoda

* Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

(e) *Difficulties with Intra-City Rescue Activities* (D_{IAR})

Group	Cities or Wards
Group-(4)	Tokyo (Meguro, Setagaya), Yokohama Sakae, Kawasaki (Tama, Miyamae), Osaka Sumiyoshi
Group-(3)	Tokyo (Nakano, Suginami, Toshima, Yokohama Kohoku, Osaka (Higashiyodogawa, Joto), **Kobe Tarumi**[*]
Group-(2)	Chiba Inage, Tokyo (Nerima, Edogawa), Yokohama (Minami, Hodogaya), Kawasaki (Saiwai, Nakahara, Takatsu), Nagoya Kita, Kyoto (Ukyo, Yamashina), Osaka (Asahi, Abeno, Higashisumiyoshi, Nishinari, Yodogawa, Tsurumi, Hirano), **Kobe Higashinada**[*], Fukuoka (Minami, Jonan)
Group-(1)	Chiba Hanamigawa, Tokyo (Bunkyo, Shinagawa, Shibuya, Kita, Arakawa, Itabashi, Katsushika), Yokohama (Kanagawa, Isogo, Totsuka, Konan), Nagoya (Mizuho, Tenpaku), Osaka (Miyakojima, Minato, Higashinari, Ikuno, Suminoe, Chuo), **Kobe** (**Nada**, **Hyogo**)[*], **Nishinomiya**[*], Fukuoka (Higashi, Sawara)
Group-(0) Mean group	Sapporo Shiroishi, Sendai (Wakabayashi, Taihaku), Tokyo (Shinjuku, Koto, Ota, Adachi), Yokohama (Tsurumi, Nishi, Kanazawa, Asahi, Midori, Seya, Izumi), Kawasaki Asao, Nagoya (Chikusa, Nakamura, Showa, Nakagawa, Minami, Moriyama, Midori), Kyoto (Kita, Kamigyo, Nakagyo, Nishikyo), **Kobe** (**Nagata**, **Suma**)[*], **Ashiya**[*], **Takarazuka**[*], Hiroshima (Higashi, Asaminami, Saeki), Fukuoka Chuo, Kumamoto
Group-(-1)	Sapporo (Kita, Higashi, Toyohira, Nishi), Aomori, Sendai (Miyagino, Izumi), Chiba (Chuo, Wakabayashi, Mihama), Tokyo (Taito, Sumida), Niigata, Nagano, Shizuoka, Hamamatsu, Nagoya (Nishi, Atsuta, Minato, Meito), Kyoto (Sakyo, Higashiyama, Shimogyo, Fushimi), Osaka (Fukushima, Konohana, Taisho), Okayama, Hiroshima (Nishi, Asakita, Aki), Takamatsu, Kochi, Fukuoka (Hakata, Nishi), Miyazaki
Group-(-2)	Sapporo (Chuo, Atsubetsu, Teine), Sendai Aoba, Chiba Midori, Tokyo Minato, Yokohama Naka, Kawasaki Kawasaki, Nagoya Higashi, Kyoto Minami, Osaka (Nishi, Tennoji, Kita), **Kobe** (**Kita**, **Chuo**, **Nishi**)[*], Hiroshima (Naka, Minami)
Group-(-3) and -(-4)	Group-(-3): Sapporo Minami, Kushiro, Hachinohe, Fukui, Nagoya Naka, Osaka (Naniwa, Nishiyodogawa), Tottori; Group-(-4): Tokyo (Chiyoda, Chuo)

[*] Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

(f) *Difficulty with Building Reconstruction* (D_{BR})

Group	Cities or Wards
Group-(6), -(5), and -(4)	Group-(6): Osaka Nishinari; Group-(5): Kyoto Higashiyama, **Kobe Hyogo**[*]; Group-(4):Osaka Ikuno, **Kobe Nagata**[*]
Group-(3)	Tokyo Toshima, Nagoya Nakamura, Kyoto Kamigyo, Osaka (Higashinari, Abeno, Sumiyoshi), Hiroshima Minami
Group-(2)	Kyoto (Kita, Shimogyo, Ukyo), Osaka (Fukushima, Asahi, Higashisumiyoshi), **Kobe** (**Nada**, **Chuo**)[*], Hiroshima Aki, Kochi, Fukuoka Hakata
Group-(1)	Sapporo Chuo, Sendai Wakabayashi, Tokyo (Shinjuku, Shinagawa, Setagaya, Shibuya, Nakano, Suginami, Kita, Arakawa), Yokohama Nishi, Kawasaki Nakahara, Nagoya Nishi, Kyoto (Sakyo, Nakagyo), Osaka (Konohana, Nishiyodogawa, Higashiyodogawa, Joto, Yodogawa, Hirano, Kita), Tottori, Okayama, Takamatsu, Fukuoka (Chuo, Minami, Jonan), Kumamoto, Miyazaki
Group-(0) Mean group	Sapporo Shiroishi, Kushiro, Hachinohe, Sendai (Aoba, Miyagino, Taihaku), Chiba Chuo, Tokyo (Bunkyo, Taito, Sumida, Meguro, Ota, Itabashi, Nerima, Adachi, Katsushika), Yokohama (Kanagawa, Naka, Minami), Kawasaki (Kawasaki, Saiwai, Takatsu, Tama), Nagano, Shizuoka, Nagoya (Chikusa, Higashi, Kita, Showa, Mizuho, Atsuta, Nakagawa, Minami), Kyoto (Minami, Fushimi, Yamashina), Osaka (Miyakojima, Minato, Taisho, Tennoji, Naniwa, Tsurumi, Suminoe, Chuo), **Kobe Higashinada**[*], **Nishinomiya**[*], Hiroshima (Naka, Higashi, Nishi, Asaminami), Fukuoka (Higashi, Nishi, Sawara)
Group-(-1)	Sapporo (Kita, Higashi), Aomori, Chiba Inage, Tokyo (Chuo, Minato, Edogawa), Yokohama (Tsurumi, Hodogaya, Isogo, Kohoku, Seya), Niigata, Fukui, Hamamatsu, Nagoya (Naka, Minami, Moriyama, Tenpaku), Kyoto Nishikyo, Osaka Nishi, **Kobe (Suma**, **Tarumi)**[*], **Takarazuka**[*]
Group-(-2)	Sapporo (Toyohira, Minami, Nishi), Chiba (Hanamigawa, Wakaba), Tokyo (Chiyoda, Koto), Yokohama (Kanazawa, Asahi), Kawasaki (Miyamae, Asao), Nagoya Meito, Ashiya, Hiroshima (Asakita, Saeki)
Group-(-3)	Sapporo Atsubetsu, Chiba Midori, Yokohama (Totsuka, Konan, Midori, Sakae, Izumi), Nagoya Midori, **Kobe** (**Kita**, **Nishi**)[*]
Group-(-4) and -(-5)	Group-(-4): Sapporo Teine, Sendai Izumi; Group-(-5): Chiba Mihama

[*] Kobe districts damaged by the 1995 Hyogoken-Nambu EQ. Higher groups have a greater seismic risk.

EARTHQUAKE DISASTER PATTERNS

Disaster Pattern Classification based on Estimated Potential Seismic Risk

Fig. 5 shows the procedure used to classify earthquake disaster patterns based on the potential seismic risk of the cities studied. As shown in the figure, a two-step procedure is used to classify the earthquake disaster pattern:

Step 1, *Classification of eight pattern groups*: Based on the groupings of potential seismic risk, *i.e.*, R_{SA}, R_{DB}, R_F, R_{RD}, D_{IAR}, D_{IRR}, and D_{BR}, to cities in Phases 1 to 4 in Tables 3(a)-(f), two patterns are identified in each phase, *HR* (high risk) and *LR* (low risk), as shown in Table 4. Then, the patterns (HR and LR) in Phases 2 to 4, which follow an event, are combined to give eight pattern groups, PaG[1] through PaG[8], as shown in Fig. 5.

Step 2, *Detailed classification of the eight pattern groups based on cluster analysis*: The eight pattern groups (PaG[1] to PaG[8]) determined in the last step are classified in detail based on a hierarchical cluster analysis (Okuno 1971), as follows:

PaG[1]: P2-LR, P3-LR, P4-LR --> PaG[1]-1, PaG[1]-2, PaG[1]-3, …
PaG[2]: P2-HR, P3-LR, P4-LR --> PaG[2]-1, PaG[2]-2, PaG[2]-3, …
PaG[3]: P2-LR, P3-HR, P4-LR --> PaG[3]-1, PaG[3]-2, PaG[3]-3, …
PaG[4]: P2-LR, P3-LR, P4-HR --> PaG[4]-1, PaG[4]-2, PaG[4]-3, …
PaG[5]: P2-HR, P3-HR, P4-LR --> PaG[5]-1, PaG[5]-2, PaG[5]-3, …
PaG[6]: P2-HR, P3-LR, P4-HR --> PaG[6]-1, PaG[6]-2, PaG[6]-3, …
PaG[7]: P2-LR, P3-HR, P4-HR --> PaG[7]-1, PaG[7]-2, PaG[7]-3, …
PaG[8]: P2-HR, P3-HR, P4-HR --> PaG[8]-1, PaG[8]-2, PaG[8]-3, …

where P2, P3, and P4 represent Phases 2 to 4, respectively.

In the hierarchical cluster analysis, Euclidean distance and Ward's method are used for each cluster, *i.e.*, the city investigated (Okuno 1971). The two patterns (HR and LR) of *Risk of Seismic Activity* (Phase 1: before an earthquake) classified in Step 1 are then incorporated in the detailed classification to investigate the seismic activity in each pattern group.

Results of Disaster Pattern Classification

The earthquake disaster patterns of typical Japanese cities, as shown in Fig. 3, were classified using Steps 1 and 2, as shown in Fig. 5. Tables 5(a) and 5(b) show the eight pattern groups obtained in Step 1. Fig. 6 shows an example of the detailed classification described in Step 2, which consists of a dendrogram of the PaG[1]-group that was computed using hierarchical cluster analysis with Euclidean distance and Ward's method (Okuno 1971 and SPSS 1996). A criterion for clustering each investigated city is defined as the standardized distance of clusters (a city, or group of cities). In this study, a distance of 5 was selected to distinguish the eight pattern groups in Table 5 in a detailed classification, based on technical and engineering considerations, as shown in Fig. 6 (PaG[1]). Tables 6(a) and 6(b) show the results of the detailed classification of PaG[1] through PaG[4], and PaG[5] through PaG[8], respectively. The following results were obtained.

1. Comparison of the classified earthquake disaster patterns makes it possible to select a city, or group of cities, where urgent earthquake preparedness measures are needed. For example, Ikuno and Nishinari wards, Osaka, classified as having the highest risk with respect to *Risk of Damage to Buildings (R_{DB})*, *Risk of Fire (R_F)*, and *Difficulty with Building Reconstruction (D_{BR})* are urgently needed for earthquake preparedness measures (PaG[6]-5 shown in Fig. 6(b)).

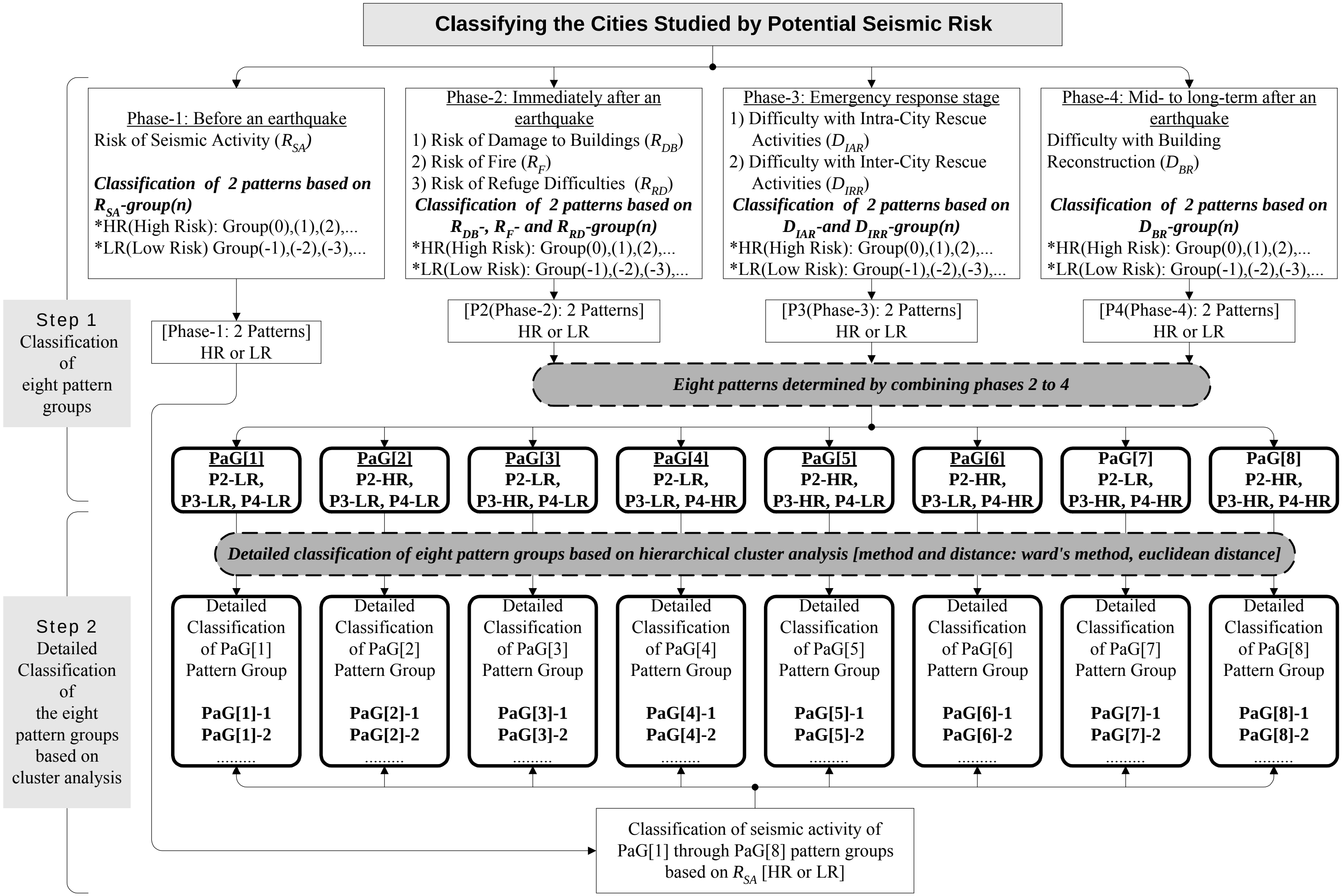


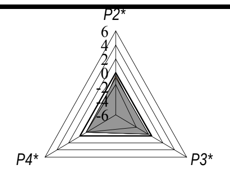
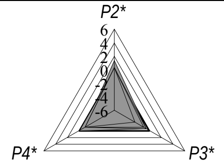
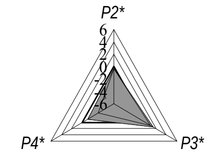
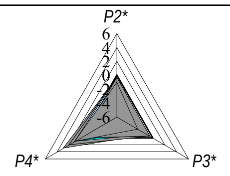
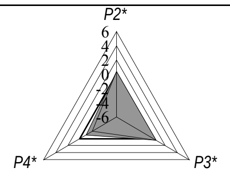
Fig. 5 Procedure for classifying earthquake disaster pattern groups based on the estimated potential seismic risk

Table 4 Subclassification into two risk groups

Potential Seismic Risk			Two subclassifications	
			HR (High Risk)	LR (Low Risk)
Phase 1	Before an earthquake	*Risk of Seismic Activity:* R_{SA}	*HR* $\geq$ *mean group**	*LR < mean group**
Phase 2	Immediately after an earthquake	*Risk of Damage to Buildings:* R_{DB}	*HR* $\geq$ *mean group** [mean values of R_{DB}, R_F *and* R_{RD}]	*LR < mean group** [mean values of R_{DB}, R_F *and* R_{RD}]
		Risk of Fire: R_F		
		Risk of Refuge Difficulties: R_{RD}		
Phase 3	Emergency response stage	*Difficulty with Intra-City Rescue Activities:* D_{IAR}	*HR* $\geq$ *mean group** [mean values of D_{IAR} *and* D_{IRR}]	*LR < mean group** [mean values of D_{IAR} *and* D_{IRR}]
		Difficulty with Inter-City Rescue Activities: D_{IRR}		
Phase 4	Mid- to long-term after an earthquake	*Difficulty with Building Reconstruction:* D_{BR}	*HR* $\geq$ *mean group**	*LR < mean group**

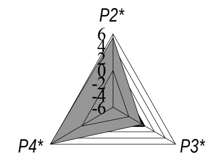
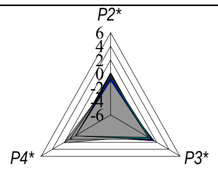
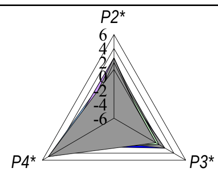
* Mean group represents group (0), as shown in Table 3(a)-(f).

Table 5 Step 1: Classification into eight patterns
(a) PaG[1] through PaG[5]

Patterns of potential seismic risk		Cities or Wards
PaG[1] P2*-LR** P3*-LR** P4*-LR**		Sapporo (Minami, Atsubetsu, Teine), Fukui, Hamamatsu, Niigata, Chiba (Wakaba, Midori, Mihama), Hiroshima Asakita, **Kobe (Kita, Nishi)*****, Yokohama (Kanazawa, Totsuka, Asahi, Midori, Izumi), Kawasaki Asao, Nagoya (Midori, Minato, Meito, Moriyama, Tenpaku, Naka) **Ashiya*****, **Takarazuka*****, Tokyo (Minato, Koto, Chiyoda, Chuo)
PaG[2] P2*-HR** P3*-LR** P4*-LR**		Yokohama (Konan, Tsurumi, Kanagawa, Isogo, Seya), Tokyo Edogawa, Osaka Nishi
PaG[3] P2*-LR** P3*-HR** P4*-LR**		Sapporo (Kita, Higashi, Toyohira, Nishi), Aomori, Sendai Izumi, **Kobe (Suma, Tarumi)** ***, Chiba (Hanamigawa, Inage), Hiroshima Saeki, Kyoto Sakyo, Yokohama Sakae
PaG[4] P2*-LR** P3*-LR** P4*-HR**		Sapporo Chuo, **Kobe Chuo*****, Hiroshima (Minami, Nishi, Aki), Takamatsu, Fukuoka (Hakata, Nishi), Chiba Chuo, Okayama, Tottori, Kushiro, Hachinohe, Sendai Aoba, Yokohama Naka, Nagoya Higashi, Osaka (Tennoji, Nishiyodogawa, Konohana, Kita), Kawasaki Kawasaki, Nagoya (Chikusa, Atsuta, Nakagawa), **Nishinomiya*****
PaG[5] P2*-HR** P3*-HR** P4*-LR**		Yokohama (Hodogaya, Kohoku), Kawasaki Miyamae

* P2: Phase-2 [R_{DB}, R_F, R_{RD}], P3: Phase-3 [D_{IAR}, D_{IRR}], P4: Phase-4 [D_{BR}]
** LR: Low Risk, HR: High Risk *** Kobe districts damaged during the 1995 Hyogoken-Nambu Earthquake

(b) PaG[6] through PaG[8]

Patterns of potential seismic risk		Cities or Wards
PaG[6] P2*-HR** P3*-LR** P4*-HR**		Hiroshima Naka, Tokyo Katsushika, Osaka (Miyakojima, Yodogawa, Tsurumi, Hirano, Minato, Taisyo, Fukushima, Suminoe, Chuo, Higashinari, Asahi, Abeno, Higashisumiyoshi, Ikuno, Nishinari, Naniwa), Kawasaki (Nakahara, Saiwai, Takatsu), Tokyo (Arakawa, Kita, Taito, Sumida, Adachi, Sinjuku, Ota, Shibuya, Bunkyo, Shinagawa, Itabashi, Nerima), Yokohama Nishi, Nagoya (Nishi, Nakamura, Showa, Mizuho, Minami)
PaG[7] P2*-LR** P3*-HR** P4*-HR**		Kochi, Shizuoka, Sendai (Miyagino, Wakabayashi, Taihaku), Miyazaki, Kumamoto, Nagano, Kyoto (Sakyo, Minami, Fushimi), Hiroshima (Higashi, Asaminami), **Kobe Higashinada*****, Fukuoka (Higashi, Sawara)
PaG[8] P2*-HR** P3*-HR** P4*-HR**		Sapporo Shiroishi, Fukuoka (Chuo, Minami, Jonan), **Kobe (Nada**, **Hyogo**, **Nagata)*****, Yokohama Minami, Nagoya Kita, Osaka (Higashiyodogawa, Joto, Sumiyoshi), Tokyo (Setagaya, Suginami, Toshima, Nakano, Meguro), Kawasaki Tama, Kyoto (Kita, Ukyo, Yamashina, Kamigyo, Nakagyo, Shimogyo, Higashiyama)

* P2: Phase-2 [R_{DB}, R_F, R_{RD}], P3: Phase-3 [D_{IAR}, D_{IRR}], P4: Phase-4 [D_{BR}]
** LR: Low Risk, HR: High Risk *** Kobe districts damaged during the 1995 Hyogoken-Nambu Earthquake

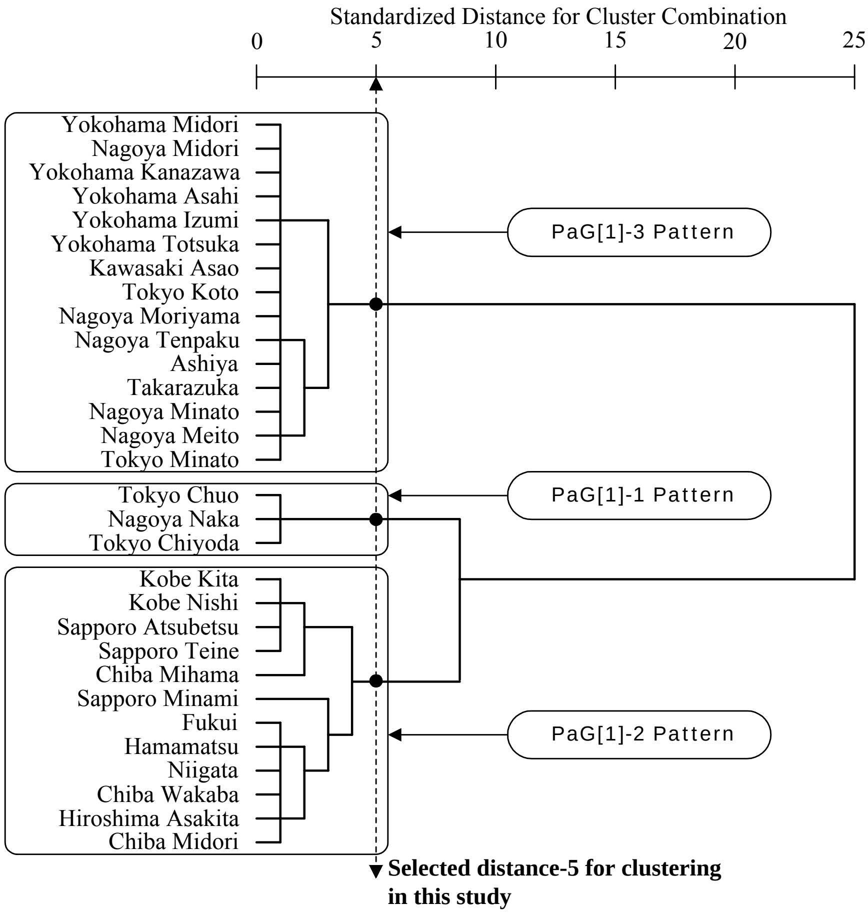
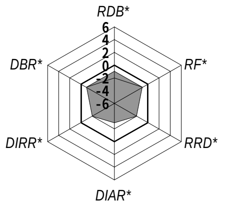
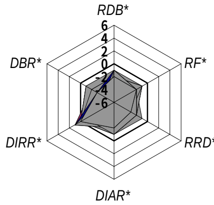
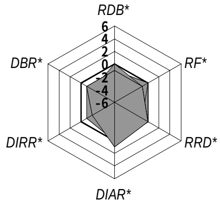
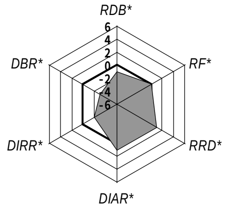
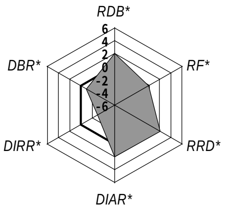
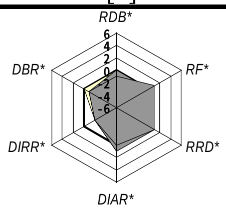
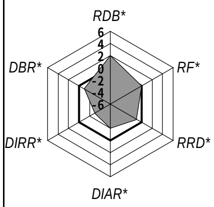
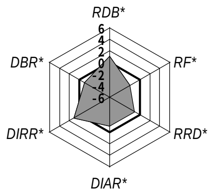
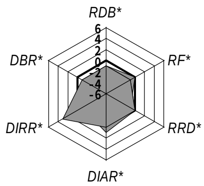
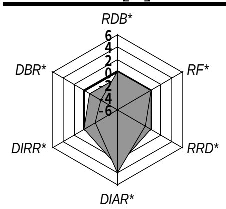
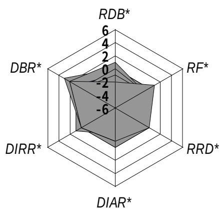
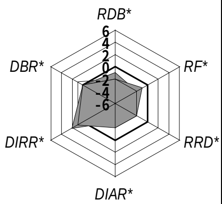
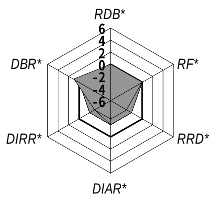
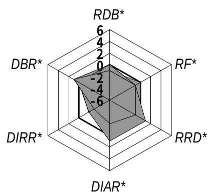


Fig. 6 An example of the dendrogram used for the detailed classification of PaG[1]-group

Table 6 Step 2: Detailed classification of the eight patterns based on cluster analysis
(a) PaG[1] through PaG[4])

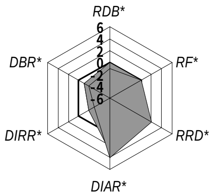
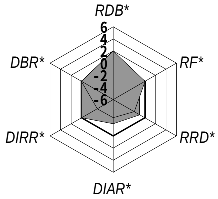
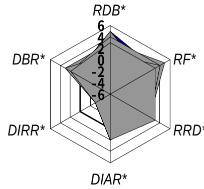
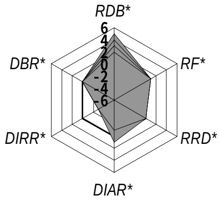
PaG[1]			PaG[2]
PaG[1]-1	PaG[1]-2	PaG[1]-3	PaG[2]-1
			
Tokyo(Chiyoda, Chuo), Nagoya Naka	Niigata, Chiba (Wakaba, Midori, Mihama), Hiroshima Asakita, Sapporo (Minami, Atsubetsu, Teine), **Kobe (Kita, Nishi)**[*]**,** *Fukui*, *Hamamatsu*	Kawasaki Asao, **Ashiya**[*], **Takarazuka**[*], *Yokohama (Kanazawa, Totsuka, Asahi, Midori)*, *Tokyo (Minato, Koto)*, *Nagoya (Midori, Minato, Meito, Moriyama, Tenpaku)*	*Yokohama Konan*

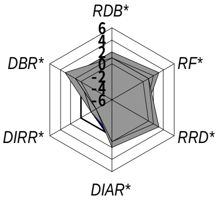
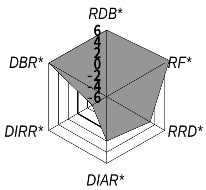
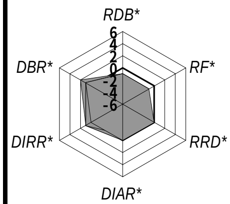
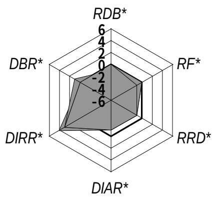
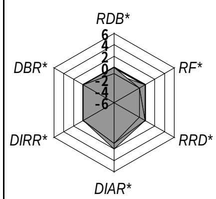
PaG[2]			PaG[3]	
PaG[2]-2	PaG[2]-3	PaG[2]-4	PaG[3]-1	PaG[3]-2
				
Tokyo Edogawa	*Yokohama (Tsurumi, Kanagawa, Isogo, Seya)*	*Osaka Nishi*	Sapporo (Kita, Higashi)	Sapporo (Toyohira, Nishi), Aomori, *Sendai Izumi*, **Kobe Suma**[*], Chiba Hanamigawa, Hiroshima Saeki, *Kyoto Sakyo*

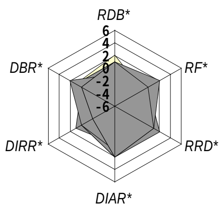
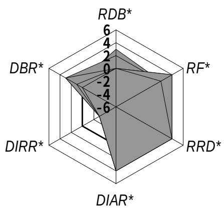
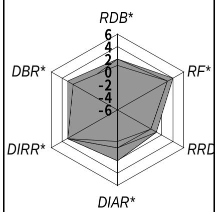
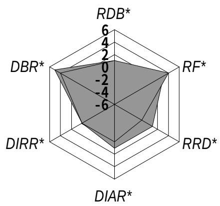
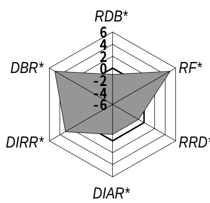
PaG[3]	PaG[4]			
PaG[3]-3	PaG[4]-1	PaG[4]-2	PaG[4]-3	PaG[4]-4
				
Chiba Inage, **Kobe Tarumi**[*], *Yokohama Sakae*	Sapporo Chuo, **Kobe Chuo**[*], Hiroshima (Minami, Nishi, Aki), Takamatsu, Fukuoka (Hakata, Nishi), Chiba Chuo, Okayama	Tottori, *Kushiro, Hachinohe, Sendai Aoba*	*Yokohama Naka, Nagoya Higashi, Osaka (Tennoji, Nishiyodogawa)*	Kawasaki Kawasaki, *Osaka (Konohana, Kita)*, *Nagoya (Chikusa, Atsuta, Nakagawa)*, **Nishinomiya**[*]

[*] Kobe districts damaged during 1995 Hyogoken-Nambu Earthquake.
Cities or wards in italics are classified as HR (high risk) for *Risk of Seismic Activity* (R_{SA}).
Others are classified as LR (low risk).

(b) (PaG[5] through PaG[8])

PaG[5]	PaG[6]		
PaG[5]-1	PaG[6]-1	PaG[6]-2	PaG[6]-3
			
Yokohama (Hodogaya, Kohoku), Kawasaki Miyamae	Hiroshima Naka, *Osaka Naniwa*	Kawasaki (Nakahara, Saiwai), *Tokyo (Katsushika, Arakawa, Kita), Osaka (Miyakojima, Yodogawa, Tsurumi, Hirano, Higashinari, Asahi, Abeno, Higashisumiyoshi)*	*Tokyo (Taito, Sumida, Adachi), Osaka (Minato, Taisyo)*

PaG[6]		PaG[7]		
PaG[6]-4	PaG[6]-5	PaG[7]-1	PaG[7]-2	PaG[7]-3
				
Kawasaki Takatsu, *Yokohama Nishi, Nagoya (Nishi, Nakamura, Showa, Mizuho, Minami), Osaka (Fukushima, Suminoe, Chuo), Tokyo (Sinjuku, Ota, Shibuya, Bunkyo, Shinagawa, Itabashi, Nerima)*	*Osaka (Ikuno, Nishinari)*	Kochi, *Shizuoka, Sendai(Miyagino, Wakabayashi, Taihaku), Miyazaki, Kumamoto*	*Nagano, Kyoto (Sakyo, Minami, Fushimi)*	Hiroshima (Higashi, Asaminami), **Kobe Higashinada***, Fukuoka (Higashi, Sawara)

PaG[8]				
PaG[8]-1	PaG[1]-2	PaG[8]-3	PaG[8]-4	PaG[8]-5
				
Sapporo Shiroishi, Fukuoka (Chuo, Minami, Jonan), **Kobe Nada*,** *Yokohama Minami, Nagoya Kita*	Kawasaki Tama, *Tokyo (Setagaya, Suginami, Toshima, Nakano, Meguro), Osaka (Higashiyodogawa, Joto, Sumiyoshi)*	*Kyoto (Kita, Ukyo, Yamashina, Kamigyo, Nakagyo, Shimogyo)*	**Kobe (Hyogo, Nagata)***	Kyoto Higashiyama

* Kobe districts damaged during 1995 Hyogoken-Nambu Earthquake.
Cities or wards in italics are classified as HR (high risk) for *Risk of Seismic Activity* (R_{SA}).
Others are classified as LR (low risk)

2. The highest risk expected in a city can be determined from the disaster pattern. For example, *Risk of Fire (R_F)* and *Difficulty with Building Reconstruction (D_{BR})* for Hyogo and Nagata wards, Kobe, which were severely damaged during the 1995 Hyogoken-Nambu earthquake are expected as the highest seismic risk (PaG[8]-4 shown in Fig. 6(b)). This information can be utilized to identify urgently required earthquake preparedness measures with the highest priority for each city.

CONCLUDING REMARKS

This study proposed a methodology for estimating a city's potential seismic risk. This methodology was based on regional characteristics derived from both macro-information and micro-information. The methodology was applied to Japanese cities, and its accuracy in assessing the potential seismic risk was determined from a comparison with observed damage resulting from the 1995 Hyogoken-Nambu Earthquake. Based on the estimated potential seismic risk of the cities studied, their earthquake disaster patterns were also investigated. The results can be summarized as follows:

1. The estimated potential seismic risk assessed using the proposed methodology compares reasonably well with actual damage observed in Kobe.
2. The proposed methodology is a useful strategy for identifying cities at high potential seismic risk, and for recommending urgently required earthquake preparedness measures.
3. The earthquake disaster pattern can be practically utilized as basic information necessary for the development of appropriate countermeasures against future earthquakes.
4. For future earthquake preparedness measures, it is recommended that the regional characteristics of a city, or group of cities, be classified and improvements that could reduce their potential seismic risk should be identified.

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