ISOSEISMAL MAP OF THE 1995 HYOGO-KEN-NANBU EARTHQUAKE

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SUMMARY

The 1995 Hyogo-ken Nanbu, Japan earthquake caused catastrophic damage in Hanshin and Awaji areas. Although many strong motion records are obtained, the distribution of the seismic intensity of the earthquake remains uncertain. To construct the isoseismal map of the Hyogo-ken Nanbu earthquake, the various damage data and the instrumental seismic intensity data are compiled, and the relations of the seismic intensity with various damage indexes are examined. The damage indexes are properly converted to the seismic intensity using the relations. The isoseismal map is estimated by overlaying the converted seismic intensity data from different damage indexes. As a result, the range of the seismic intensity 6- is extended from Toyonaka city in Osaka Prefecture to Seidan town in Awaji Island. The range of the seismic intensity 6+ is extended from Takarazuka city in Hyogo Prefecture to Ichinomiya town in Awaji Island.

INTRODUCTION

The seismic intensity 7 in the Japan Meteorological Agency (J.M.A.) scale was observed for the first time during the 1995 Hyogo-ken Nanbu, Japan earthquake, which caused catastrophic damage in Hanshin (Osaka and Kobe cities) and Awaji areas. Although strong motion records were obtained at many observation stations, there are uncertainties remaining in the spatial distribution of the seismic intensity. Analysis of various damage data is necessary to reveal the distribution of the seismic intensity in the affected area.

The seismic intensity has been surveyed from a compilation of human perception, movement of object and the resultant casualties. After the Hyogo-ken Nanbu earthquake, the J.M.A. adopted the instrumental seismic intensity for grasping the seismic intensity rapidly and objectively using the accelerogram since April 1996. The instrumental seismic intensity is defined to be consistent with the previous seismic intensity [Japan Meteorological Agency, 1996].

In this paper, we combine the instrumental seismic intensity data with the questionnaire seismic intensity data and various damage data such as the building damage survey data and the overturning rate of tombstones in order to construct the isoseismal map of the Hyogo-ken Nanbu earthquake. The relations between the seismic intensities and various damage indexes are examined. The damage indexes are properly converted to the seismic intensity using the relations. The area of the seismic intensity 6- (weaker) and 6+ (stronger) in Hanshin and Awaji areas is estimated from overlaying the converted seismic intensity data.

DISTRIBUTION OF DAMAGE AND SEISMIC INTENSITY

Instrumental Seismic Intensity

Strong motion records were obtained at many observation stations during the Hyogo-ken Nanbu earthquake [Architectural Institute of Japan, 1996]. The distribution of the instrumental seismic intensity computed from the

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strong motion records is shown by number in Fig.1. The number in bracket in Fig.1 shows the instrumental seismic intensity roughly estimated from the relation of the instrumental seismic intensity with peak ground acceleration or velocity proposed by Tong et al. (1996). The observation stations with the seismic intensity of more than 6 are distributed in the southern part of Kobe city, Takarazuka city, Amagasaki city and Akashi city. The seismic intensity in Osaka city is about 5. Strong motion observation stations are deployed densely in the southern part of Kobe city and Osaka city, while the number of observation stations is not enough in the other areas. Therefore it is difficult to draw the isoseismal map only from the distribution of the instrumental seismic intensity.

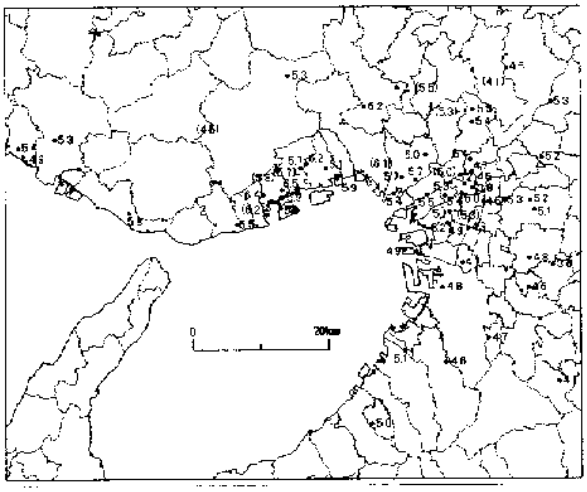

Figure 1: Distribution of instrumental seismic intensity

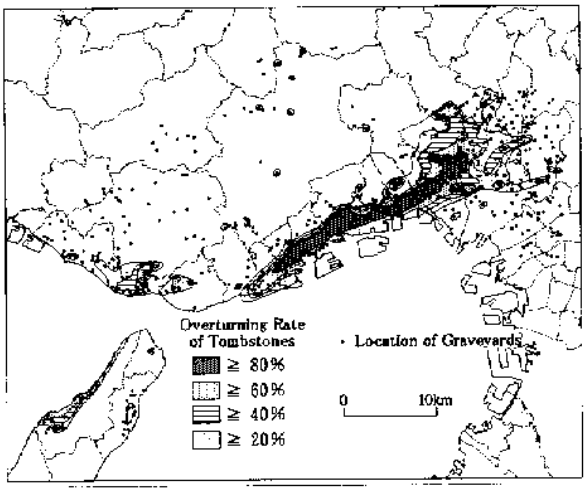

Figure 2: Distribution of overturning rate of tombstones

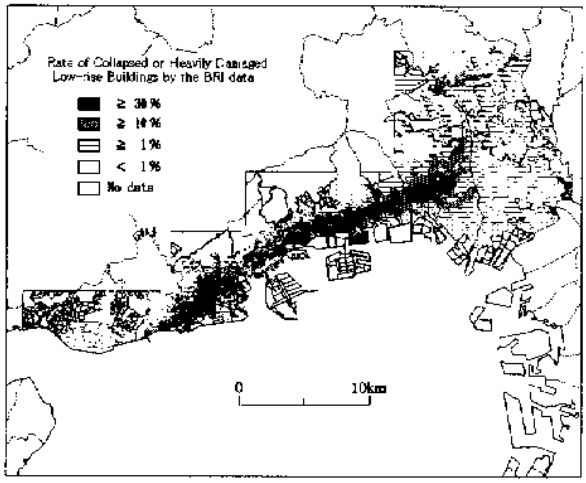

Figure 3: Distribution of rate of collapsed or heavily damaged low-rise buildings by the BRI data

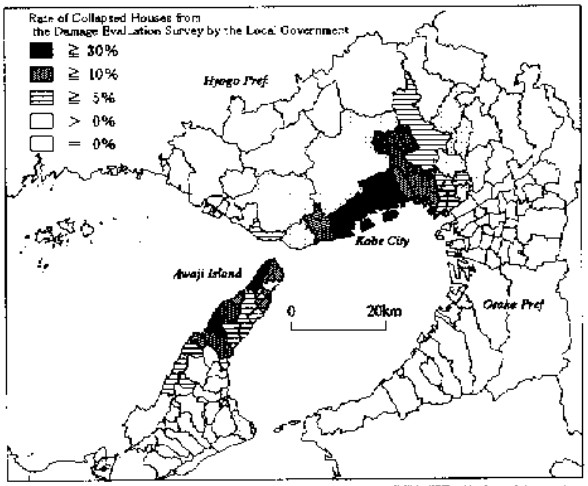

Figure 4: Distribution of rate of collapsed houses from the damage evaluation survey

Overturning Rate of Tombstones

The damage survey of tombstones was performed by several groups after the Hyogo-ken Nanbu earthquake. For instance, Kawasaki et al. (1996) investigated the overturning rate of tombstones in 441 graveyards located in Osaka city to Awaji Island. The location of the graveyards and the contour maps of the overturning rate of tombstones are shown in Fig.2. The area of the higher overturning rate is extended from Suma ward in Kobe city to Itami city. The area of the overturning rate of 80% or more agrees well with the area of the J.M.A. seismic intensity 7.

Building Damage

Damaged buildings were surveyed by several groups after the earthquake [e.g. Working Group for the 1995 Hyogo-ken Nanbu Earthquake Damage Investigation, 1995]. The number of damaged buildings for each section of a city or a ward was investigated by two groups, whose results were compiled and published by Building Research Institute (1996). This data is referred as "the BRI data" hereafter. In the BRI data, the damage levels of the building are judged from an appearance of the building and are classified in 7 categories, "collapsed or heavily damaged", "moderate damaged", "light damaged", "no damage", etc. The building damage survey was conducted in and around Kobe city.

Figure 3 shows the distribution of the rate of collapsed or heavily damaged low-rise buildings. The area of the rate of collapsed or heavily damaged low-rise buildings of 30% or more is similar to the area of the seismic intensity 7 in the J.M.A. scale. The area of the rate of 1% or more is extended from Tarumi ward in Kobe city to Takarazuka, Amagasaki and Itami cities.

The local governments in the affected area performed the damage evaluation survey for houses in the larger area than the investigated area by the BRI data. The damage criteria of the BRI data and of the damage evaluation survey data by local government are different, which are based on the structural damage of buildings and the loss of property value, respectively. The distribution of the rate of collapsed houses from the damage evaluation survey by the local governments is shown in Fig.4. The area of the higher rate of collapsed houses is distributed along the Nojima fault and the Rokko faults. Collapsed houses are distributed in Osaka city to Awaji Island.

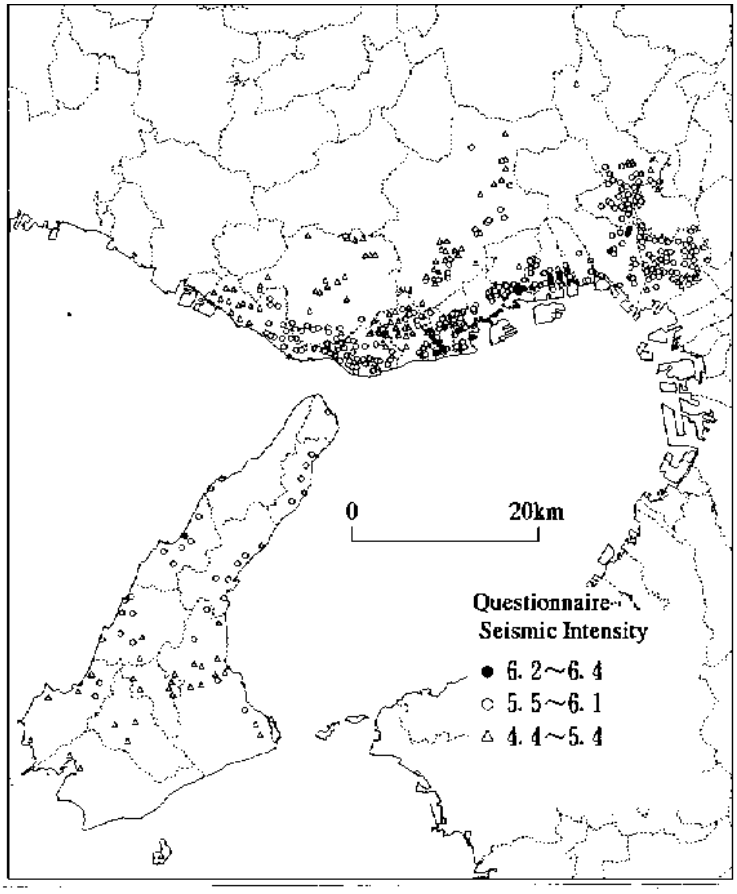

Figure 5: Distribution of questionnaire seismic intensity

Questionnaire Seismic Intensity

The questionnaire seismic intensity survey for the Hyogo-ken Nanbu earthquake conducted by several groups. One of them is performed by Takada and Kashima (1996) who investigated in Akashi, Kobe, Nishinomiya, Ashiya, Amagasaki, Takarazuka, Itami cities and Awaji Island. The distribution of the questionnaire seismic intensity for a section of a city, a ward or a town is shown in Fig.5. The area of the questionnaire seismic intensity 6.2 or more shows comparatively good agreement with the area of the J.M.A. seismic intensity 7. However, it is difficult to estimate the isoseismal map only from the questionnaire seismic intensity data because the data is distributed sparsely, especially in the northern part of Awaji Island.

Features of Damage and Seismic Intensity Data

To construct the isoseismal map from the damage distribution data, it is necessary that 1) the damage data is given for a comparatively small section and 2) the damage data is distributed widely and uniformly in an area of interest. Table 1 shows the conditions of 1) and 2) for each damage data and seismic intensity data mentioned above.

The data of the instrumental seismic intensity are distributed densely in the urban area, however there are few observation stations in the other areas. The data of the overturning rate of tombstones are widely distributed, but its distribution is sparse in some areas. The rates of collapsed or heavily damaged buildings by the BRI data are obtained in smaller section, however the investigated area is limited in the vicinity of Kobe city. The rates of collapsed houses from the damage evaluation survey by the local governments are distributed widely, however most results of them are obtained for a municipality unit. The data of the questionnaire seismic intensities are obtained for a section of a city, a ward or a town, however the distribution is sparse.

From the above mentioned features of the damage and seismic intensity data in this study, the isoseismal map of the earthquake is estimated from overlayng of the damage data and the seismic intensity data. The isoseismal map in Hanshin area is estimated from the instrumental seismic intensity, the overturning rate of tombstones, the rate of collapsed or heavily damaged buildings by the BRI data and the questionnaire seismic intensity. The isoseismal map in Awaji Island is estimated from the overturning rate of tombstones, the rate of collapsed houses by the local governments and the questionnaire seismic intensity.

Table 1: Features of damage and seismic intensity data

Seismic Intensity and Damage Data	(1) Size of Section	(2) Distribution (Range)	(Uniformity)	Estimation of Isoseismal Map# (Hanshin area)	(Awaji Island)
Instrumental Seismic Intensity	small (strong motion station)	little narrow (Hanshin area)	not uniform	○	—
Overturning Rate of Tombstones	small (graveyard)	little wide (Hanshin area and the northern part of Awaji Island)	little uniform	○	○
Rate of Collapsed or Heavily Damaged Buildings by the BRI data	little small (block, sectin of a city or a ward)	narrow (in and around Kobe city)	uniform	○	—
Rate of Collapsed Houses by Local Governments	large (town,district,municipality)	wide (Hyogo pref.,Osaka pref.,etc.)	uniform	×	○
Questionnaire Seismic Intensity	little large (section of a city, a ward or a town)	little wide (Hanshin and Awaji areas)	little uniform	○	○

○:used, ×:not used, —:not available

RELATIONS BETWEEN VARIOUS DAMAGE INDEXES AND SEISMIC INTENSITY

Relation between Questionnaire Seismic Intensity and Seismic Intensity

The relation of the questionnaire seismic intensity (IQ) with the instrumental seismic intensity (IINSTR) computed from the strong motion records is shown by open circle in Fig.6. The IINSTR increases with increase of the IQ, however the IINSTR is generally larger than the IQ and the discrepancy of both intensities becomes larger with increase of the seismic intensity. The regression equation derived by using the least square method is as following:

According to Eq. (1), the seismic intensities 5.5 and 6.0 are corresponded to the questionnaire seismic intensities 5.50 and 5.82, respectively. Hereafter the questionnaire seismic intensity converted to the seismic intensity is referred as "the modified questionnaire seismic intensity".

$$I_{INSTR} = 1.40 \cdot I_Q - 2.14 \quad (I_Q > 5.5) \qquad (1)$$
$$= I_Q \quad (I_Q \leq 5.5)$$

Relation between Overturning Rate of Tombstones and Seismic Intensity

The relations between the seismic intensity and the overturning rate of tombstones during the Hyogo-ken Nanbu earthquake and the other earthquakes in Japan are shown in Fig.7. The relations show scatter, but the overturning rate of tombstones seems to increase with increase of the seismic intensity. The regression equation derived from the overturning rates of tombstones in terms of the seismic intensity is shown by thick line in Fig.7. According to the regression line, the seismic intensities 5.5 and 6.0 is corresponded to the overturning rates of tombstones of 30% and 70%, respectively.

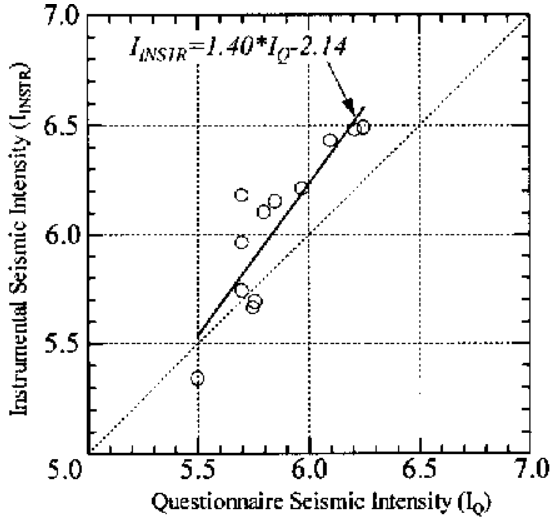

Figure 6: Relation between questionnaire seismic intensity and instrumental seismic intensity

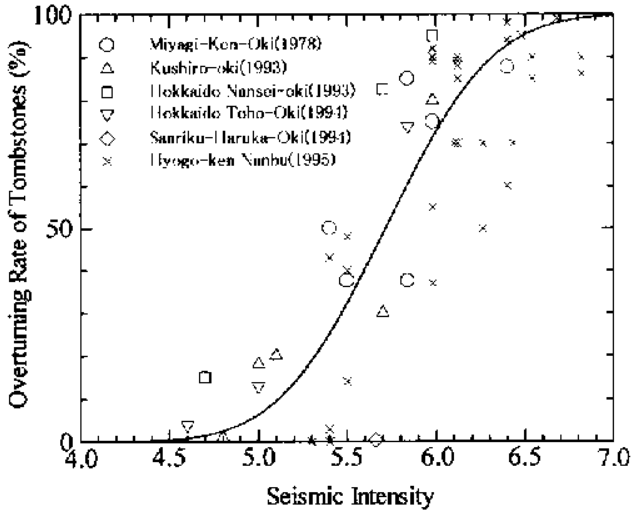

Figure 7: Relation between overturning rate of tombstones and seismic intensity

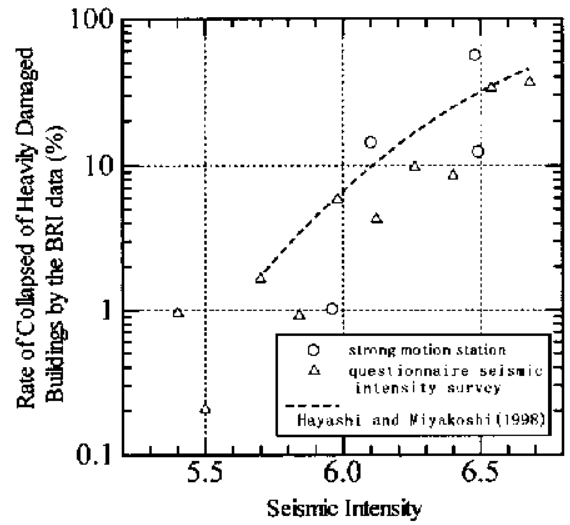

Figure 8: Relation between rate of collapsed of heavily damaged low-rise buildings and seismic intensity

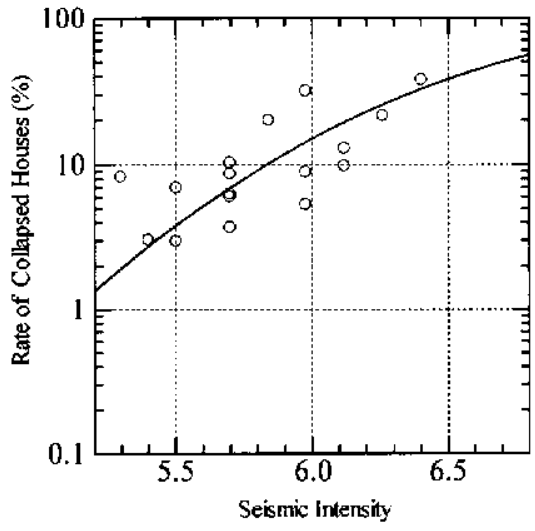

Figure 9: Relation between rate of collapsed houses and seismic intensity

Relation between Rate of Collapsed or Heavily Damaged Buildings and Seismic Intensity

Figure 8 shows the relation of the rate of collapsed or heavily damaged buildings by the BRI data with the instrumental seismic intensity and with the modified questionnaire seismic intensity. Also the damage ratio function of buildings proposed by Hayashi and Miyakoshi (1998) is presented by dashed line in Fig.8. The relations show good agreements with each other. From the relations, the seismic intensities 5.5 and 6.0 correspond to the rates of collapsed or heavily damaged buildings of 1% and 8%, respectively.

Relation between Rate of Collapsed Houses and Seismic Intensity

The relation between the rate of collapsed houses by the damage evaluation survey and the modified questionnaire seismic intensity is shown by open circle in Fig.9. The regression line derived from the rate of collapsed houses in terms of the modified questionnaire seismic intensity is shown by thick line in Fig.9. According to the regression line, the rates of collapsed houses of 4% and 15% correspond to the seismic intensities 5.5 and 6.0, respectively.

ESTIMATION OF ISOSEISMAL MAP.

Table 2 summarizes the relations of the seismic intensity with the damage indexes to estimate the isoseismal map of the Hyogo-ken Nanbu earthquake. The isoseismal map in Hanshin area is estimated from the rate of collapsed or heavily damaged buildings by the BRI data, the overturning rate of tombstones and the questionnaire seismic intensity which are converted to the seismic intensities using the relations shown in Table 2 together with the instrumental seismic intensity . As a result, the range of the seismic intensity 6- is extended about 50km from the southern part of Toyonaka city to Akashi city. The range of the seismic intensity 6+ is extended from Takarazuka city to Suma ward in Kobe city and is situated in the part of Akashi city.

Also the isoseismal map in Awaji Island is estimated from the rate of collapsed houses, the overturning rate of tombstones and the questionnaire seismic intensity which are converted to the seismic intensities using the relations shown in Table 2. As a result, the range of the seismic intensity 6- is extended about 40 km from Awaji town to the northern part of Seidan town. The range of the seismic intensity 6+ is extended from the middle part of Hokudan town to the middle part of Ichinomiya town in the northwestern side of the Island and is situated in the part of Higashiura and Tsuna towns in the southeastern side of the Island.

Table 2: Relations of seismic intensity with damage indexes

Damage Index and Seismic Intensity	Seismic Intensity		
	5+	6-	6+
Instrumental Seismic Intensity		5.5	6.0
Overturning Rate of Tombstones (%)		30	70
Rate of Collapsed or Heavily Damaged Buildings by the BRI data (%)		1	8
Rate of Collapsed Houses by the Local Governments (%) [Awaji Island]		4	15
Questionnaire Sesimic Intensity		5.50	5.82

Figure10 shows that the area of the seismic intensity 6- and 6+ estimated from the damage distributions and the area of J.M.A. seismic intensity 7. The range of the seismic intensity 6- is extended from the southern part of Toyonaka city in Osaka prefecture to the northern part of Seidan town in Awaji Island. The range of the seismic intensity 6+ is extended from Takarazuka city in Hyogo prefecture to Ichinomiya town in Awaji Island. The ranges of the seismic intensity 6- and 6+ are about 85 km and 65 km in length, respectively. The areas of the seismic intensity 6- and 6+ are about 390 km2 and 130 km2, respectively.

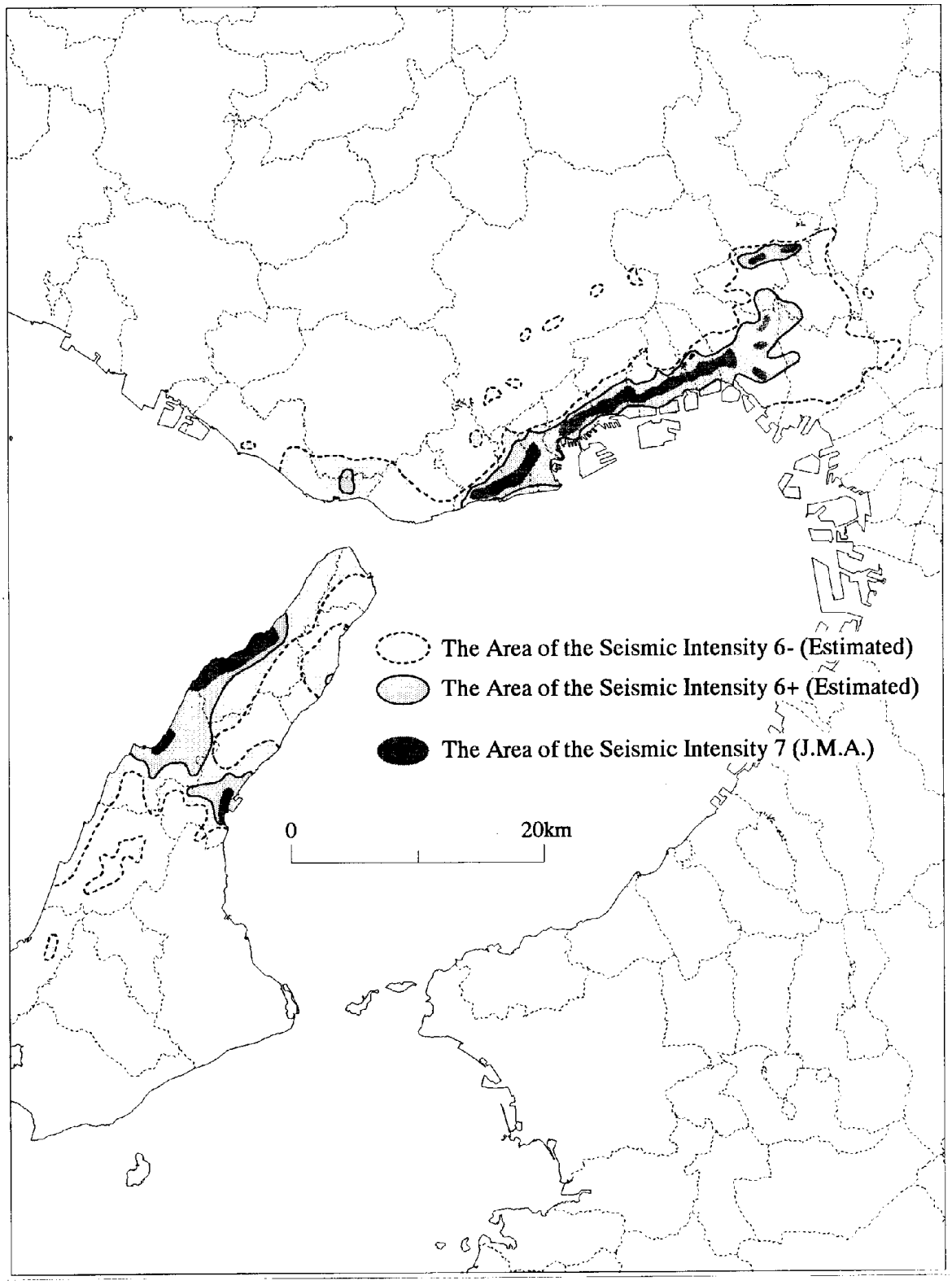

Figure 10: Isoseismal map of the Hyogo-ken Nanbu earthquake estimated from damage distributions

CONCLUSIONS

To construct the isoseismal map of the Hyogo-ken Nanbu earthquake, the various damage data and the instrumental seismic intensity data are compiled and the relations of the seismic intensity with various damage indexes are examined. The isoseismal map in Hanshin area is estimated from the rate of collapsed or heavily damaged buildings by the BRI data, the overturning rate of tombstones, the questionnaire seismic intensity and the instrumental seismic intensity. Also the isoseismal map in Awaji Island is estimated from the rate of collapsed houses from the damage evaluation survey by the local governments, the overturning rate of tombstones and the questionnaire seismic intensity. As a result, the isoseismal map of the Hyogo-ken Nanbu earthquake over the Hanshin-Awaji area is obtained.

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