Micro-Distribution of Peak Ground Acceleration in Hanshin Area Estimated by Seismograph Data and Seismic Intensity obtained by Questionnaires for the 1995 Great Hanshin Earthquake

by

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ABSTRACT

In this paper the distribution of peak ground acceleration during the 1995 Great Hanshin Earthquake is estimated by the shape interpolation method. In order to grasp the detailed seismic intensity, we distributed questionnaires within the struck area and calculated the seismic intensity from such questionnaires.

As a result, the distribution of the large values of acceleration is coincident with distribution of the damage in struck areas. The distribution of high level of seismic intensity obtained from questionnaires corresponds to the distribution of the level 7 of the JMA intensity.

Key Words: Shape Interpolation Method, Seismic Intensity, Questionnaires, Peak Ground Acceleration, Geographical Information System

1. INTRODUCTION

Urban functions in highly developed cities are greatly dependent upon lifeline systems such as electric power, gas, water and communication networks. In view on decision making of strategies for restoration workings as well as on the prevention of secondary disasters due to earthquake damage, it is indispensable to obtain information of earthquake damage to lifeline systems as quickly and exactly as possible. Several seismographs are generally arranged at the vicinity of important facilities of lifeline systems in order to obtain records for seismic ground motions which are greatly related to the earthquake damage to lifeline systems. Because it is neither economical nor possible to arrange many seismographs for the whole lifeline systems, Takada et al.[1] proposed a method to estimate seismic ground motions at arbitrary locations through the seismograph data observed at limited locations. Such method which uses the shape interpolating function of F.E.M. and B.E.M. is applied to seismograph data observed during the 1995 Great Hanshin Earthquake in order to estimate the distribution of peak ground acceleration in wide range areas.

The scale of ground intensity as considered by the Japan Meteological Agency (hereafter JMA) is one based on index which present the objective ground intensity. However, it is well known that the observatories of JMA are not placed in areas close each other, so the JMA intensity is very macroscopic. By the other hand, there are 2 facts of really concern following the 1995 Great Hanshin Earthquake. One is related with the unpublished boundaries of intensity by the JMA and the other is that the distribution of JMA intensity was not observed and estimated sufficiently to be treated numerically. By taking into account the above-mentioned situations, the ground intensity is evaluated herein by applying the methodology proposed by Ota et al.[2], in which the ground intensity is obtained as the result of questionnaires in order to grasp the distribution of ground intensity.

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2. ESTIMATION OF GROUND MOTION BY APPLYING A METHODOLOGY WHICH USES SHAPE INTERPOLATING FUNCTION

2.1 Methods

The method used in this paper to estimate seismic ground motions at arbitrary locations through the seismograph data observed at limited locations considers the shape interpolating function used in F.E.M. and B.E.M.[3]. This shape interpolation functions make the values given by a dispersive function to be treated as a continuous function. In F.E.M., the interpolation function is continue and is used to interpolate values between the nodes.

At first, lets consider that peak ground acceleration is observed at the four points of a square-shape area, the peak ground acceleration at any arbitrary point within this square-shape area is possible to be estimated by using both the Eq.2.1 and the shape interpolating function, which is expressed as follows:

$$A_{max}(\xi,\eta)=N_1(\xi,\eta)A_1+N_2(\xi,\eta)A_2+N_3(\xi,\eta)A_3+N_4(\xi,\eta)A_4 \quad (2.1)$$

in which

$$N_1(\xi,\eta)=0.25(1-\xi)(1-\eta)$$
$$N_2(\xi,\eta)=0.25(1+\xi)(1-\eta)$$
$$N_3(\xi,\eta)=0.25(1+\xi)(1+\eta)$$
$$N_4(\xi,\eta)=0.25(1-\xi)(1+\eta).$$

Note: A_i(i=1-4) is the peak ground acceleration at i-th observatory.

However, in practice the seismographs are not arranged at the four corners of a perfect square, but set up at the four corners of a quadrilateral. So it is necessary to modify the estimating equation for an arbitrary quadrangle shape.

For instance, lets consider an array of seismographs located at the corners of a square. On this way, we can estimate easily the peak ground acceleration at the point (x,y) by using Eq.2.2, if the correspondence of the point (x,y) in global coordinates to the point (ξ,η) in local coordinates exists. The relationship between global and local coordinates can be represented as follows:

$$x=\sum_{i=1}^{4}N_i(\xi,\eta)x_i, \quad y=\sum_{i=1}^{4}N_i(\xi,\eta)y_i \quad (2.2)$$

where x_i and y_i are x and y coordinates of i-th observatory, respectively.

On the same way, estimation can be done if the shape is either hexagonal or octagonal one. By considering the fact that the more the observation points, the better the accuracy of estimation, the octagonal shape is used in this research.

The observed acceleration value can be significantly affected by the difference of ground conditions such as soft ground and hard one. As shown in Fig.2.1, we firstly convert the observed value from surface to bedrock. Secondly, the peak ground acceleration is interpolated on bedrock and lastly the interpolated acceleration is converted from bedrock to surface. Thus, the peak ground accelerarion at ground surface can be obtained by multiplying the amplification factor c_G related with ground classification as follows:

$$A_{max}=\sum_{i=1}^{m}N_i(\xi,\eta)A_i\frac{c_G}{c_{Gi}} \quad (2.3)$$

where c_{Gi} is the amplification factor of the i-th observetory.

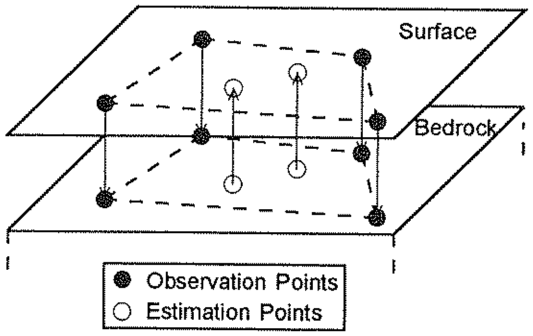

Fig.2.1 Concept of estimation of acceleration taking into account the spatial distribution.

Regarding to the procedure to determine the value of c_G, firstly we established 20 ground classifications; secondly representative boring log of each classifications is extracted; thirdly, the ground model is made up based on the boring log and lastly we conduct nonlinear response analyses by using the made up model. We evaluate the value of c_G from the maximum acceleration of the input seismic wave and the response one. Fig.2.2 and Fig.2.3 show respectively the extracted boring logs and the relationship between the maximum acceleration of the input seismic wave and the response one.

2.2 Data

After the 1995 Great Hanshin Earthquake, owing to the cooperation of not only some universities and public agencies such as Kobe University and JMA but also to the cooperation of private companies such as *Osaka Gas* and *Kansai Electric Power Company*, we got many valuable ground motion data. We arranged east longitude, north latitude, peak ground accelerations and peak ground velocities of these databases which are obviously in terms of observed positons (east longitude and north latitude).

2.3 Results

2.3.1 Monitoring Network

At first, it was necessary to set up the monitoring network in order to estimate the distribution of ground acceleration. The monitoring network of the horizontal component is shown in Fig.2.4. Monitoring network is arranged for the whole Kobe area which is divided by 7 areas based on Geographcal Information System (hereafter GIS). We use the octagonal shape function in order to avoid the extrapolation and also to improve the accuracy of the estimation.

2.3.2 Results of Estimation

Fig.2.5 shows the distribution of horizontal acceleration estimated by applying the above-mentioned method. Each area is divided into the Cho-moku, the acceleration is presented by the representative value of the Cho-moku. In this figure the blank area is the area of which we have no data in GIS.

From Fig.2.5, in Kobe, Nishinomiya and Ashiya Cities where the earthquake damage was heavy, the estimated acceleration shows more than 600 Gals. In nearby places such as Itami and Takarazuka Cities the estimated acceleration is also large. It is typical that the distribution of large acceleration values has a L-type form. Compared with the distribution of intensity level 7 by JMA, areas such as Suma, Nagata, Chuo, Nada and Higashinada Ward have very large accelerations. In Tarumi Ward, although the estimated acceleration shows a large value, the distribution of the estimated acceleration shows a proper result.

The method used in this paper has the possibility to take into account the set up conditions of the monitoring network. For the case in which the number of observation points is small, the weight of an observation point will be high and the estimated result will be much influenced by the observed value. We set up a monitoring network a long time after the occurrence of the 1995 Great Hanshin Earthquake by using the observation points. Due to that, it took a long time to set up the monitoring network and calculate the (ξ,η) which is used in Eq.2.3, it prompt to the need to be prepared, it implies that the monitoring network should be arranged before the occurrence of an earthquake. If there is a point in which data cannot be obtained, we must set up the monitoring network again after earthquake. In order to grasp the damage information just after eathquake and to help making the reconstruction strategies, the estimation of ground motion needs to be conducted as soon as possible after earthquake. Thus, we should set up as many seismographs as possible in order to be able to arrange multiple networks and to evaluate quickly the seismic response in the unexpected situation.

2.4 Verification of Accuracy

In this section we verify the accuracy of

Fig.2.2 Extracted boring logs.

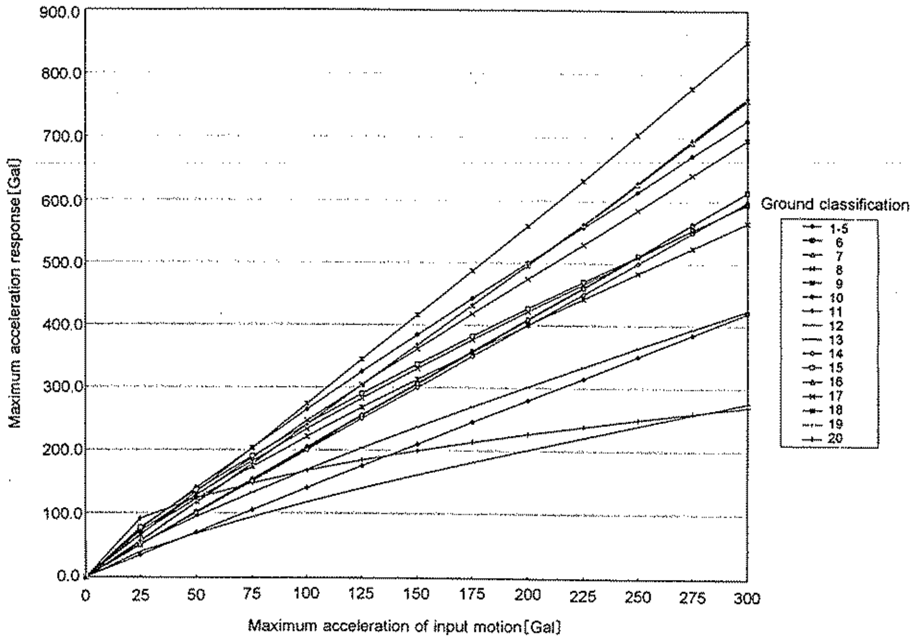

Fig.2.3 Relationship between the maximum acceleration of the input motions and the response.

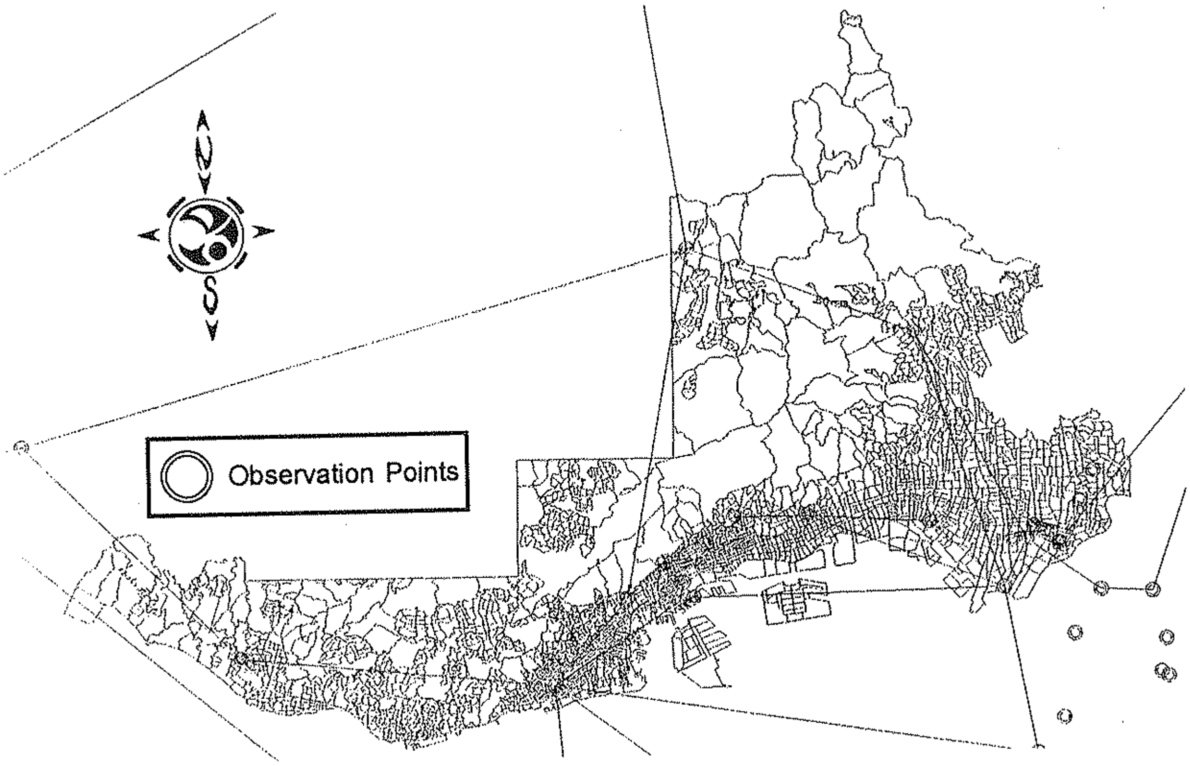

Fig.2.4 Monitoring network of the horizontal component.

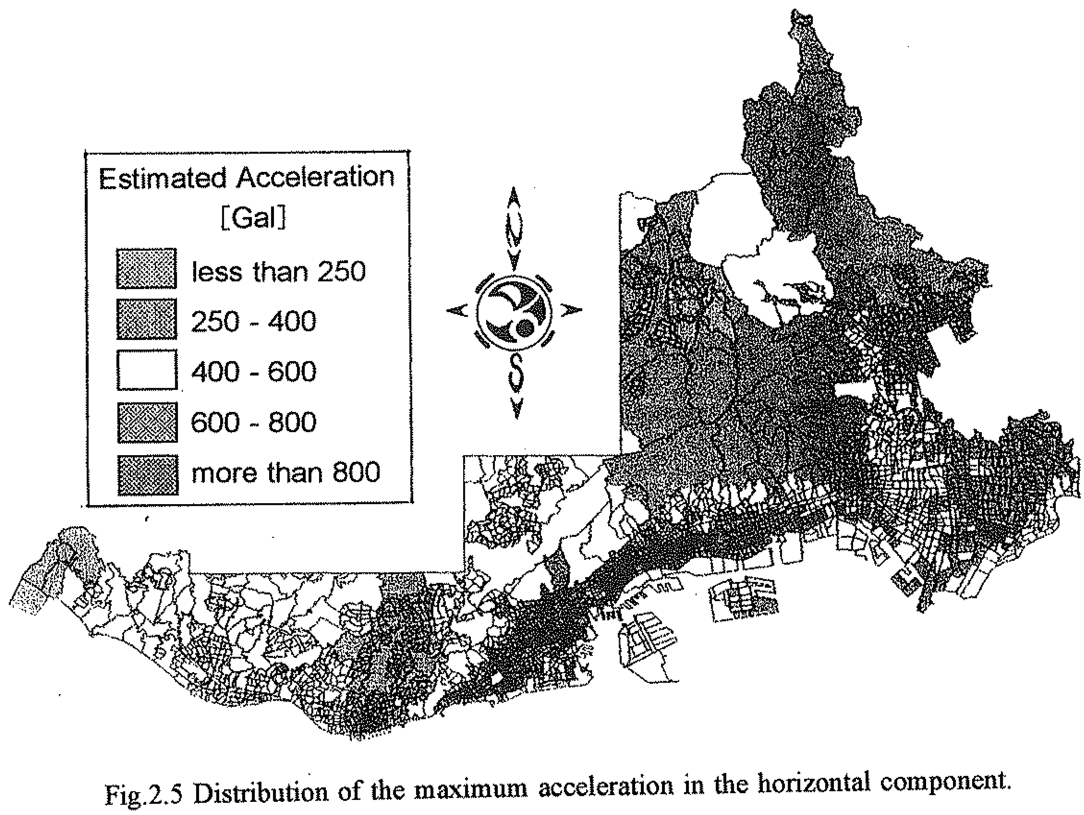

Fig.2.5 Distribution of the maximum acceleration in the horizontal component.

estimation by the shape interpolation method. For the horizontal component which has many records, some observation points are located inside the monitoring network on GIS. Thus, it is possible to estimate the acceleration at the observation points and compare them with the observed values. The result is shown in Fig.2.6.

As is shown in Fig.2.6, the estimated acceleration is coincident with the observed one except at one point. It is considered that the estimated acceleration at the point is much influenced by the low acceleration observed near there. So, if the number of observation points is small and a close-space network is not arranged such as in the case of the 1995 Great Hanshin Earthquake, the shape interpolation method cannot express the local site amplification. However, for the whole area struck by an earthquake, the shape interpolation method is possible to apply.

3. SEISMIC INTENSITY OBTAINED BY QUESTIONNAIRES

3.1 Methods

3.1.1 Distribution of Questionnaires

In order to grasp the detailed distribution of ground intensity obtained by questionnaires, it is necessary to distribute many questionnaires. By this way, thanks to the aid of the Board of Education and the principal committee in the objective area, we distributed the questionnaires directly to 189 public elementary schools and junior high schools. Fig.3.1 shows the distribution area of questionnaires.

The number of distributed questionnaires is more than 20000, and the collection ratio is more than 80%. Table 3.1 shows the collection

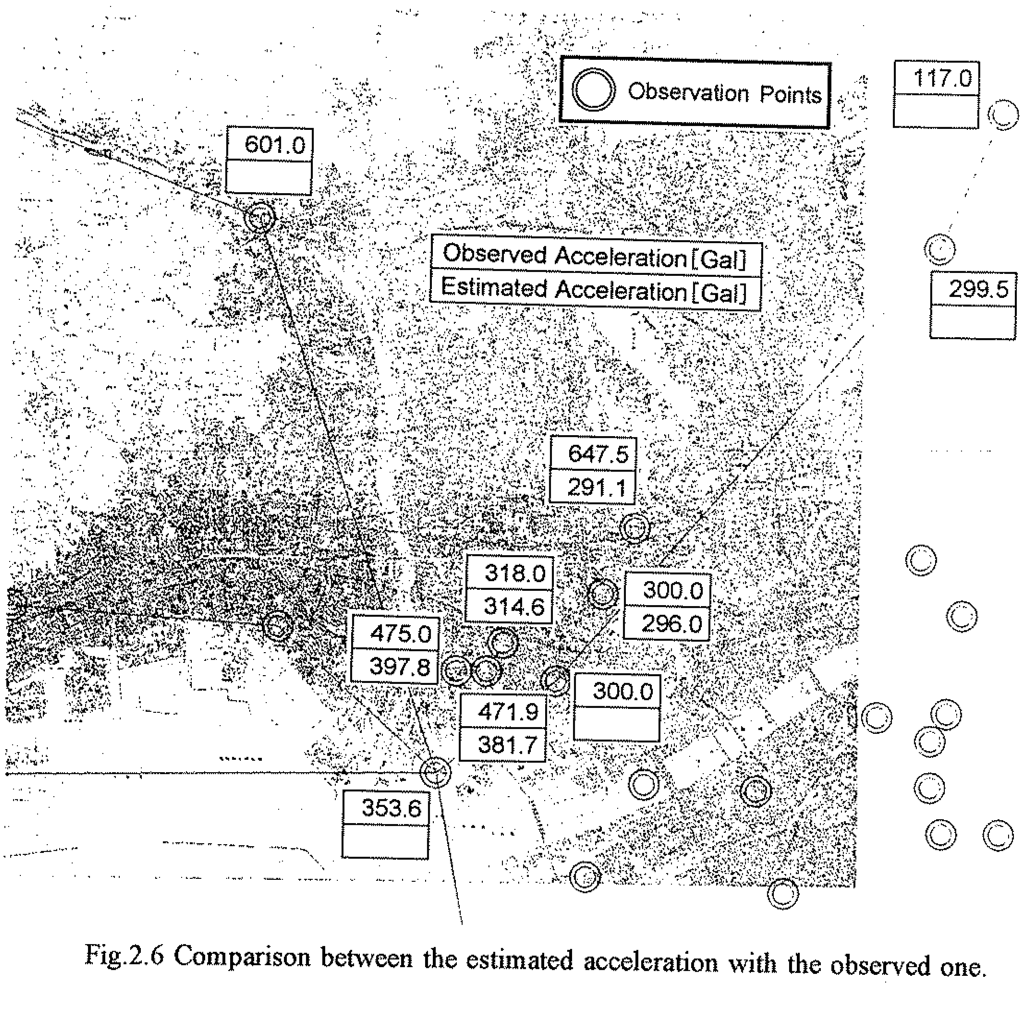

Fig.2.6 Comparison between the estimated acceleration with the observed one.

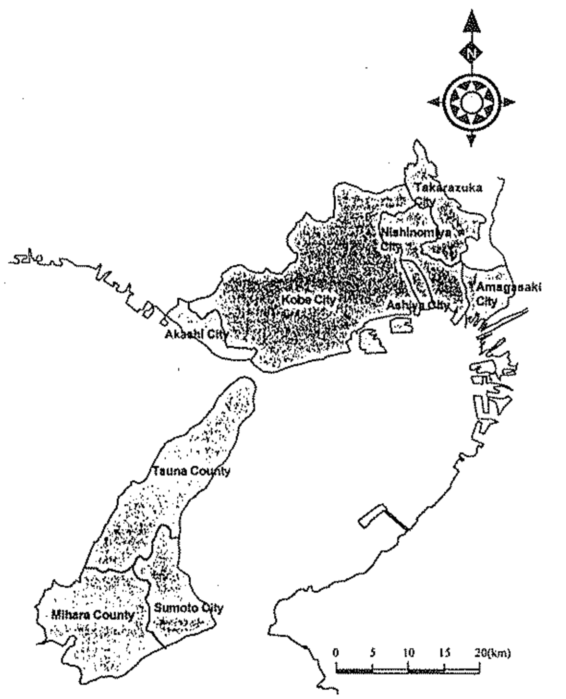

Fig.3.1 Distribution area of questionnaires.

Table 3.1 Collection ratio.

City or County	Number of Junior high school	Collection Ratio(%)	Number of Effective Answers
Takarazuka	12	81.4	1,097
Nishinomiya	11	83.8	1,072
Amagasaki	22	70.5	1,624
Ashiya	3	86.2	255
Itami	0	0	75
Kawanishi	0	0	18
Kobe	82	87.3	8,571
Akashi	12	82.5	1,283
Sumoto	5	90	538
Tsuna	6	90	1,364
Mihara	7	90	500
Subtotal	160		16,397
	Number of Elementary School		
Tsuna	29	90	2,549
Total	189		18,946

ratio and the number of effective answers. The collection ratio is the ratio between the collected questionnaires and the distributed questionnaires, and the "effective" means that the address at the 1995 Great Hanshin Earthquake of the person who answered the questionnaire is able to be specified. Further, the collection ratio in Awaji Island is an estimate, because we could not grasp the exact number of distributed questionnaires.

3.1.2 Evaluation of Ground Intensity

In this paper, the method for evaluation of ground intensity is as follows. The ground intensity is established in order that it can be read from a low level to a high one varying proportionally the selected number for the questioned item becomes greater. As the ground intensity obtained by questionnaires is based on the JMA intensity, the category number has a number from one to seven for each item. But the ground intensity obtained by questionnaires is created for earthquake levels less than 6 in JMA intensity. It implies that the intensity level 7 of JMA is not presented sufficiently.

Two concepts are introduced in the ground intensity obtained by questionnaires, one is a condition factor that takes into account that people who answered the questionnaire are not necessarily under the same situation, and the other is an intensity factor to quantify the answer for the sensuous response. The former is related with the location details of the answering person and accounts the difference in the kind, the floor number and the age of the house where the answering person was during earthquake. It is presented mostly respect to a wooden house of one story. The latter is the factor that presents the relation between each items. The item which answer the seismic response of houses is the basic item. If the frequency distribution of the answer for the i-th item is similar to the one for the basic item, the category number of the i-th item corresponds to the one of the basic item. Thus, the intensity factor is presented by the relative amount to the basic item and is computed statistically based on some earthquakes. The intensity factor I for each answering person based on the questionnaire is presented as follows:

$$I=\frac{\alpha}{N_e}\cdot\sum_{i}^{N_e} m_i\cdot\beta \tag{3.1}$$

where α, m_i and N_e are the condition factor, the category number for the i-th item and the number of effective answers in the item concerning to the ground intensity obtained by questionnaires respectively. β is the intensity factor for m_i. The summation is conducted about only effective answers. The ground intensity obtained by questionnaires I_Q is calculated by converting the intensity factor given to each person by Eq.3.1 into effective double digits of the JMA intensity. The conversion equation is expressed as follows:

$$I_Q=2.958\cdot(I-1.456)^{0.547} \quad (3.2).$$

3.2 Results

3.2.1 Preliminary Investigation

As above-mentioned the ground intensity proposed by Ota et al. is established for earthquakes of intensity levels less than 6 in the JMA intensity. Respect to the 1995 Great Hanshin Earthquake, it is possible to state that damage was severe and it was the first time that level 6 of the JMA intensity was surpassed. In order to verify the application to this earthquake, we conducted a preliminary investigation sixth months after the earthquake (July '95) with students of our laboratory. The number of answering persons was 30.

The student's locations at the time the earthquake occurred were Kobe, Ashiya, Nishinomiya, Kakogawa, Sakai and Osaka City. Table 3.2 shows the total amount. The average of intensity factor is 4.843 and the standard deviation is 0.789. As shown in this table, the intensity factor is very high in seriously damaged areas and it becomes lower according the epicentral distance is long. Thus, the evaluation of ground intensity by questionnaires for the 1995 Great Hanshin Earthquake is considered to be appropriated.

3.2.2 Distribution Characteristics

Fig.3.2 and Fig.3.3 show the distribution of

Table 3.2 Total amount of preliminary investigation.

No.	City	Ward	Town	Cho-moku	Seismic Intensity Factor	Seismic Intenisty obtained from Questionnaires	JMA Intensity
1	Kobe	Higashinada	Motoyamanaka	3	5.694	6.5	7
2	Kobe	Higashinada	Mikage	Nishihirano	5.565	6.4	7
3	Kobe	Higashinada	Sumiyoshiyamate	7	4.330	5.3	6
4	Kobe	Higashinada	Uozakikita	1	5.229	6.1	7
5	Kobe	Nada	Shinoharakita	3	4.255	5.2	6
6	Kobe	Nada	Nadakita	6	6.219	7.0	7
7	Kobe	Nada	Rokkodai	1	4.313	5.3	6
8	Kobe	Nada	Jouchi	4	5.258	6.1	7
9	Kobe	Nada	Takaha	5	4.651	5.6	6
10	Kobe	Nada	Shinoharaminami	3	5.859	6.7	7
11	Kobe	Nada	Shinoharadai		4.388	5.3	6
12	Kobe	Nada	Shinoharanaka	5	4.750	5.7	7
13	Kobe	Nada	Yuminogi	2	5.020	5.9	7
14	Kobe	Nada	Ichinosan		4.347	5.3	6
15	Kobe	Nada	Yahata	1	4.760	5.7	7
16	Kobe	Nada	Biwa	1	5.587	6.4	7
17	Kobe	Nada	Yuminogi	2	5.040	5.9	7
18	Kobe	Chuo	Kitamotomachi	4	4.346	5.3	6
19	Kobe	Suma	Yokoo	9	3.687	4.6	6
20	Kobe	Nishi	Ikawadani	Junwa	4.815	5.7	6
21	Kobe	Nishi	Ikawadani	Arise	4.711	5.6	6
22	Kobe	Kita	Seiwadai	2	4.348	5.3	6
23	Ashiya		Kasuga	No.13	5.505	6.4	7
24	Nishinomiya		Nakamaeda	7	5.818	6.6	7
25	Nishinomiya		Koshien	5th Street	4.922	5.8	6
26	Nishinomiya		Takasu	1	4.798	5.7	6
27	Osaka	Minato	Yahataya	1	4.460	5.4	4
28	Osaka	Yodogawa	Higashimikuni	6	4.013	4.9	4
29	Sakai		Nonoi	No.735	4.404	5.3	unknown
30	Kakogawa		Yoneda	Hiratsu	4.187	5.1	unknown

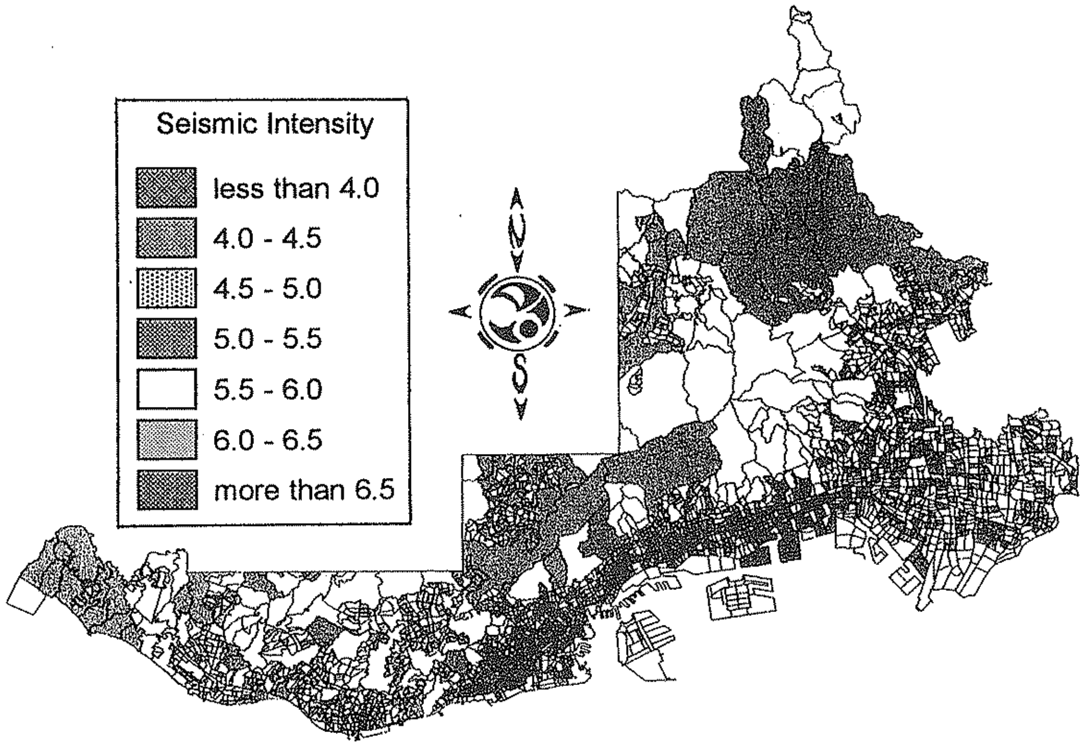

Fig.3.2 Distribution of seismic intensity obtained by questionnaires for each Cho-moku.

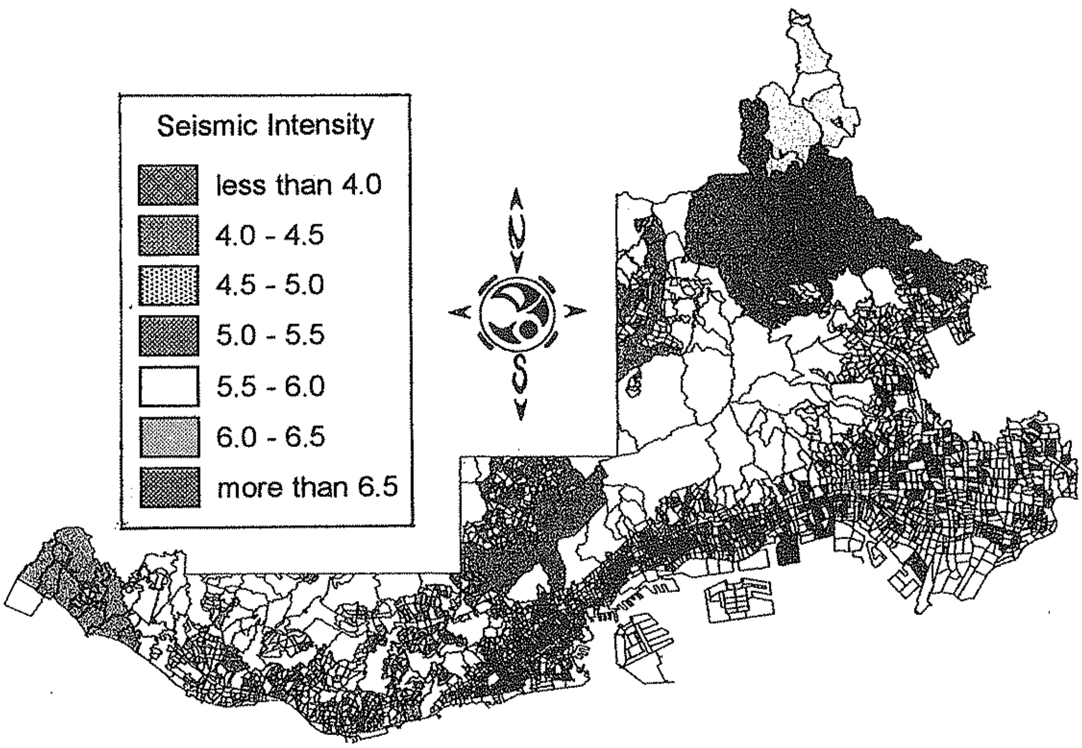

Fig.3.3 Distribution of seismic intensity obtained by questionnaires for each Cho-Cho-moku.

the seismic intensity obtained by questionnaires calculated for each Cho-moku and for each Cho-Cho-moku which has at least three answering persons, except for Awaji Island, north of Kita Ward, and Nishi Ward. The distribution shown in Fig.3.2 corresponds to that of intensity level 7 by JMA. The method considered herein is suspected to be applicable for earthquakes in which the intensity is more than the level 6 of JMA. It means that a detailed study may be possible.

Regarding to the JMA intensity, at south-east areas of Kobe, south area of Nishinomiya, Ashiya and a part of Takarazuka City, the level is 7. The intensity level in other areas was 6. Respect to the seismic intensity obtained by questionnaires, at north areas of Takarazuka City, south-east area of Kita Ward, Suma Ward, north of Tarumi Ward in Kobe City the intensity is lower in the level 5, while for at the north of Mt. Rokko and south-east areas of Akashi City the intensity is higher in the level 5. The distribution of level 7 and higher level 6 is in harmony with distribution of level 7 of JMA intensity except in the south-east area of Akashi City in which the intensity is large part of level 6. Taking into account that ground intensity is constant and the attenuation of distance is negligible within 5 km from the fault, the structural damage in Akashi City is different between the east and west areas. Thus, it is possible to say that the seismic intensity was greatly affected by local conditions in this area.

Fig.3.4 shows the cumulative relative frequency distribution of the seismic intensity obtained by questionnaires at the area where the JMA intensity level is 6 and 7. As shown in Fig.3.4, the boundary intensity between the level 6 and 7 by JMA corresponds to level 6.0 of those obtained by questionnaires.

By the other hand, Fig.3.5 shows the relationship between the fault distance and the seismic intensity obtained by questionnaires. The equation of regression is given by the method of least squares, and is expressed as follows:

$$I_Q = -0.05 \cdot d + 6.02 \tag{3.3}$$

where I_Q is the seismic intensity obtained by questionnaires and d (km) is the fault distance. The objective faults are Nojima, Suwayama and Ashiya fault. As the seismic intensity by questionnaires is computed for every Cho-moku, the fault distance is calculated as the shortest distance between the fault and the center of gravity of the Cho-moku. According to Eq.3.3, if the distance is longer than about 90 km respect to the above-mentioned faults, the seismic intensity obtained by questionnaires becomes less than 1.4.

As was also aforementioned, the seismic intensity proposed by Ota et al., in which a weight is put on each item for the sensuous response of the answering person, the intensity factor is computed by linear summation of the

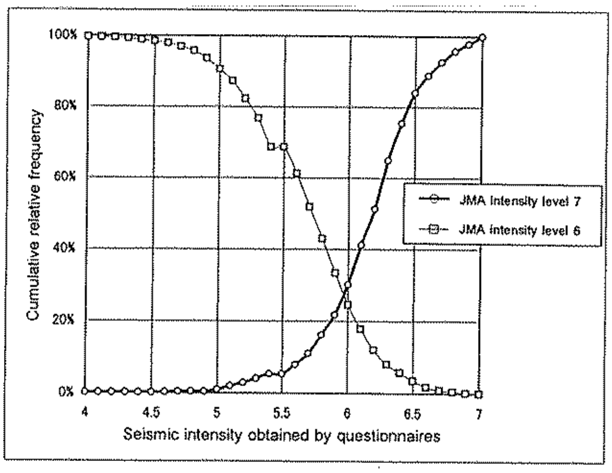

Fig.3.4 Cumulative relative frequency distribution of the seismic intensity obtained by questionnaires.

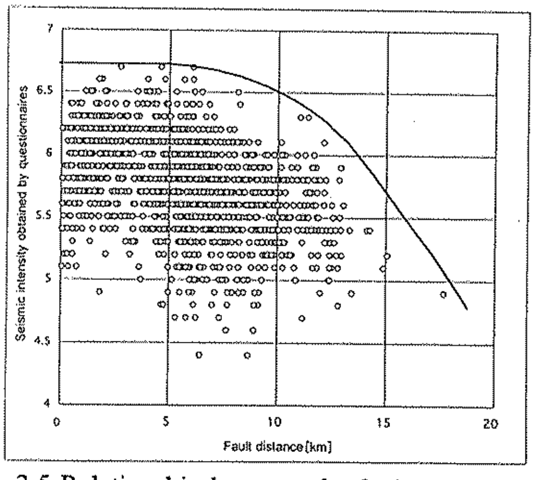

Fig.3.5 Relationship between the fault distance and the seismic intensity obtained by questionnaires.

weight and is converted into the JMA intensity by the equation based on past earthquakes. And in parallel form, the seismic intensity obtained by questionnaires is also calculated. The conversion equation is regressed by 32 data sets, but due to these data sets under level 5 of JMA intensity, the equation is inadequate to be applied to the 1995 Great Hanshin Earthquake. For this purpose, we propose a new conversion equation by using the data of the 1995 Great Hanshin Earthquake for future research. Fig.3.6 shows the relationship between the intensity factor and the JMA intensity, on this way the new conversion equation is as follows:

$$I_Q=2.334 \cdot L_n(I)+2.538 \qquad (3.4).$$

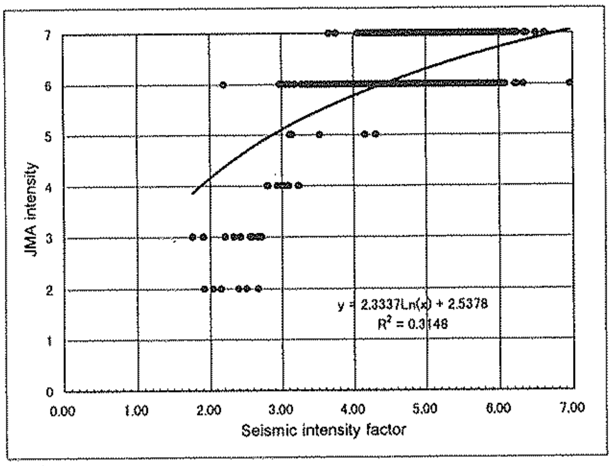

Fig.3.6 Relationship between the JMA intensity and the seismic intensity factor.

By this way, we estimated the relationship by applying the expression proposed by Midorikawa et al.[5]. Fig.3.7 shows the relationship between the seismic intensity obtained by questionnaires with the overturning rate of tombstones, the regression equation is as follows:

$$Y=5.7963 \cdot L_n(I_Q)-9.6795 \qquad (3.5).$$

Since both the objective area is concentrated to high level intensity areas and the data of low level is few, the equation which calculate the seismic intensity obtained by questionnaires gives a little high values. In the future, it would be necessary to accumulate the data and to apply the convenient regression equation.

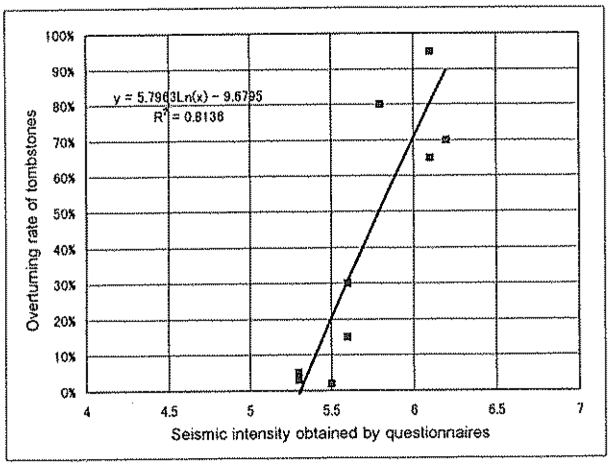

Fig.3.7 Relationship between the seismic intensity obtained by questionnaires and the overturning rate of tombstones.

3.3 Discussion

3.3.1 Relationship to the Overturning Rate of Tombstones

There is a convenient method for evaluation of the seismic intensity which is based on the overturning rate of tombstones[4]. For the grasp of the distribution of the seismic intensity obtained by questionnaires it is necessary to distribute questionnaires as many as possible and also to conducte it before people forget the sensuous response. Thus, in order to measure the seismic intensity in a simple form, it is useful to express the relationship between the seismic intensity obtained by questionnaires to the overturning rate of tombstones.

3.3.2 Relation to Records of Peak Ground Motion

Next, we examine the relationship between records by seismographs and the seismic intensity obtained by questionnaires. Fig.3.8 and Fig.3.9 show relationships for the peak ground acceleration (hereafter PGA[Gal]) and peak ground velocity (hereafter PGV[Kine]) respectively. This PGA data is the observed value. This PGV data is computed by integration of the time history of the acceleration in which a part corresponds to the observed value. As shown in Fig.3.9, the PGV of the 8th pier of Kobe port is very large compared with the

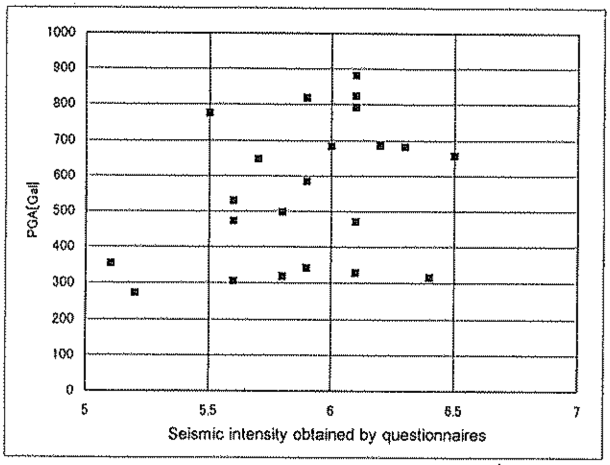

Fig.3.8 Relationship between the PGA and the seismic intensity obtained by questionnaires.

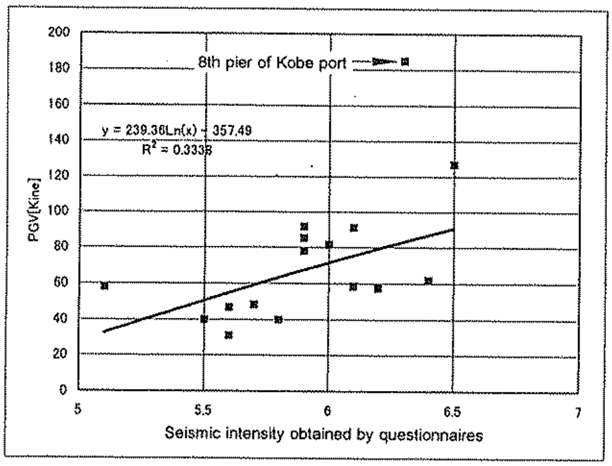

Fig.3.9 Relationship between the PGV and the seismic intensity obtained by questionnaires.

seismic intensity obtained by questionnaires. On this way, it is possible to consider that recorded seismic waves have long periods due to nonlinearities of the ground at the 8th pier of Kobe port. These figures also show that the PGV has more relation to the seismic intensity obtained by questionnaires than the PGA. The reason is that the seismic intenisty obtained by questionnaires is calculated by a medium which is the housings. Further the damage ratio of houses is more related to the PGV than the PGA. The regression equation by the method of least squares permits to relate the PGV and the seismic intensity obtained by questionnaires, which is as follows:

$$PGV=239.36 \cdot L_n(I_Q)\text{-}357.49 \qquad (3.6).$$

The regression of data corresponding to the 8th pier of the Kobe port was excluded.

4. CONCLUSIONS

We have estimated the distribution of peak ground acceleration in wide range areas by applying the observed data. The distribution of the estimated acceleration more than 600 Gals is coincident with the distribution of the heavy damaged areas. Further compared with the distribution of the level 7 of JMA intensity, an appropiated result was obtained. Also we have verified the accuracy of the estimation, as result the shape interpolation method is considered to be possible to be applied even if the local site amplification is not given.

Next, we have distributed questionnaires densely and calculated the seismic intensity by the collected questionnaires. As result, the distribution of the high level of seismic intensity obtained by the questionnaires corresponds to the distribution of the level 7 of the JMA intensity.

Also, we estimated the relationship to the ratio of the fallen tombstones and the peak ground motions and proposed the regression equations which express the relationship with the seismic intensity obtained by the questionnaires.

REFERENCES

[1]Takada, S., Takatani, T. Ogawa, Y. & Fukui, S. : An Estimating Method of Seismic Ground Motions for Monitoring System. Journal of Structural Engineering, 1994, Vol.40A, 1151-1160

[2]Ota, H., Goto, N. & Ohashi, H. : A Questionnaire Survey for Estimating Seismic Intensities. Bulletin of the Faculty of Engineering, Hokkaido University, 1979, No.92, 117-129

[3]Washizu, H., Miyamoto, H., Yamada, Y., Yamamoto, Y. & Kawai, T. : Handbook of Finite Element Method I, Baifukan, 1981

[4]Omori, F. : Investigation on the Nobi

Earthquake, Oct. 28 1891. Report by Survey Bureau for Earthquake Disaster Prevention, 1899, Vol.28, 79-95
[5]Midorikawa, S. & Fujisawa, K. : Isoseismal Map of the Hyogo-Ken Nanbu Earthquake In and Around Kobe City Estimated from Overturing of Tombstones. J. Struct. Constr. Eng., AIJ, 1996, No.490, 111-118