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Seismic Intensity Research : 1990 Luzon Earthquake

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1. INTRODUCTION

The Philippine earthquake hit Luzon Island on July 16th, 1990. With a magnitude of 7.8 it is among the world's largest earthquakes to occur on land. The affected area covered 120 kilometers. Left lateral strike slip faults caused a horizontal dislocation extending to 5.0 m. The fault appeared between Gabaldon in Nueva Ecija Prov. and Imugan in Nueva Vizcaya Prov. This fault is considered to be related to the Digdig Fault, which belongs to the Philippine Fault System. This Philippine Fault System runs through central Luzon to the southeast and northwest (Figure 1).

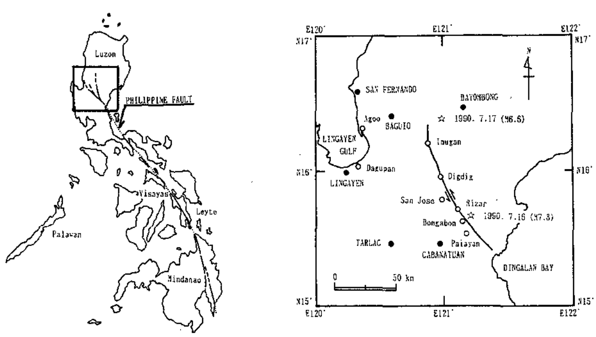

Fig. 1 Location of epicenters and seismic fault of the 1990 Philippine Earthquake.

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Unfortunately, this earthquake has not left any record of strong motion seismogram in the seismic source region. This disaster research has to be carried out in the absence of this critical information. Compared to the 1985 Mexico earthquake and the 1989 Loma Prieta earthquake we are faced with a significant obstacle in doing this disaster research. The main purpose of this researh is to predict the intensity of seismic motion and its effects as accurately as possible ; , and try to extract some information in the absence of a strong motion seismographic record. Previous earthquake research has confirmed there are various differences within damaged areas. Even in relatively small areas the extent of damage varies. This earthquake also indicated a similar phenomenon. Therefore, we are aiming to find out the most accurate extension of the motion intensity, and try to construct a seismic microzoning map.

This research was carried out by the second Philippine Earthquake damage investigation team by the Architectural Institute of Japan.

2. EARTHQUAKE DESCRIPTION

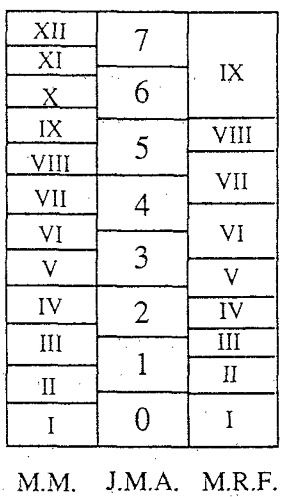
The U. S. Gelogical Survey (USGS) indicated that the earthquake's time of origin was July 16th, 7 : 26 U.T. Local time was 16 : 26. USGS said the epicenter of the quake was 110 km. north/northeast of Manila, near Bongabon (north latitude 15.7° , east longitude 121.2°). The depth of source was 25 km, magnitude of 7.8. Strong after shocks were reported, which were 6.1 and 6.6 in magnitude {recorded at 18 : 06 and 21 : 14 on the 17th (UT)}.

According to Nakata's[1] group analysis this seismic fault appeared along the existing active fault line. Overall, the fault displays a relatively plain and straight shape. Also, as predicted the fault plane shows a relatively simple shape until the deep center. In an unappearing area near Rizal, the fault is divided into two segments. The north segment runs to N 20° W and south segment runs to N 45° W of average fault striking. By using the moment tensor inversion method which uses long period surface wave, Abe[2] worked on the earthquake fault mechanism solution and reported this results. The fault coincides with the same direction and movement as the Digdig Fault, which is part of the Philippine Fault System. Abe noted that the maximum aftershock occurred at the end of the north area of the fault. The seismic noted 3.6×10^{27} dyn・cm. The size of the main fault plane measures 120 km × 20 km. The crust rigidity 3×10^{11} dyn/cm^2. According to crust rigidity, Abe decided that the average fault displacement is 5.0 meters and the average stress drop to be 48 bar. The northern end of the fault is estimated to be located 30 km east of Baguio.

In addition Ando's group[3] noticed that the damage is concentrated in Bagio and Agoo, which are 30 to 50 km from the fault. Through the dispersion of damage it is difficult to explain fault and geographic effects. Moreover, Ando, predicted the existence of a sub-fault beneath Bagio and Agoo ; and, he executed aftershock observations. Later, he reported the existence of this sub-fault, which crosses the main fault. By all means, we anticipate fauther research in order to discover the seismic source mechanism.

3. DAMAGE DESCRIPTION & RESEARCH BY PHILIPPINE INSTITUTE

Not only in Nueva Ecija and Nueva Vizcaya but in Benguet, Pangasinan, Tarlac, and La Union damage took place. About 2,000 people died also 3,500 people were injured. About 22,000 thousand buildings were destroyed. Total number of evacuees reached 1,600, 000. Though there was damage in a wide range on area along this fault, it was most heavily concentrated away from the epicenter {Baguio in Benguet, Agoo and Aringay in La Union}, located near the end of the fault. Reinforced concrete hotels were also damaged. There were many office and university buildings damaged or destroyed. In the mountainous parts of Nueva Ecija, Nueva Vizcaya, and Benguet, numerous landslides occurred and major roads were blocked, which caused a suspension of rescue recovery. The alluvial soft zone of the coastal side of Lingayen Bay experienced liquefaction ; especially at Dagupan city in Pangaisinan. Buildings and pier supports were damaged. Also some bridges were ruined. A Philippine organization reported the distribution of seismic intensity. Figure 1 illustrates the intensity of the earthquake all over the Philippines. The Philippines used the Modified Rossi-Forrel Intensity Scale {not the ordinary Rossi-Forrel}, both methods differ after grade intensity level 7.[4] Figure 3 illustrates Luzon's intensity distribution[5] by the Philippine



M.M. ; Modified Mercalli Intensity Scale
J.M.A ; Japan Meteorological Agency Intensity Scale
M.R.F. ; Modified Rossi-Forel Intensity Scale

Fig. 2 Relationship of seismic intensity Scales.

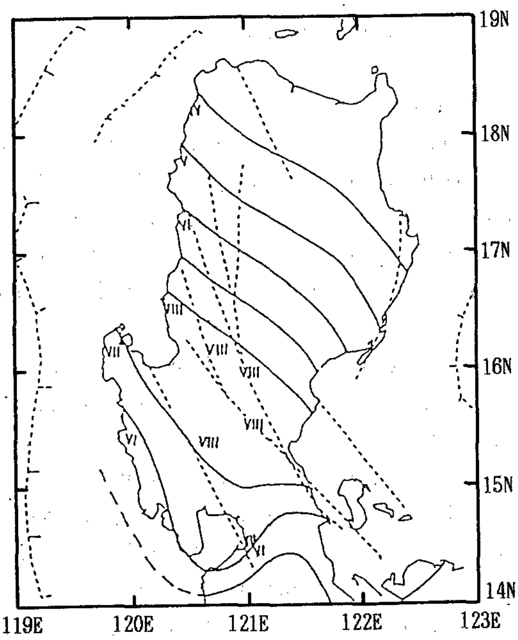


Fig. 3 Isoseismal map made by Philippine Institute of Volcanology and Seismology.

Table 1 Reported seismic intensities of main cities.

Main Cities	Intensity
MANILA	VI～VII
QUEZON	VI
CABANATUAN	VI～VIII
TARLAC	VIII
DAGUPAN	VIII
AGOO	VIII
BAGUIO	VIII～IX

Institute of Volcanology and Seismology (PHIVOLCS). Analysis in this distribution map indicates a grade 8, including a wide range along the fault. It was hard to find out the detailed intensity by local area.

4. INTENSITY ESTIMATION BY QUESTIONNAIRE SURVEY

4.1 Survey Description

(1) Survey Sheet

The format of the questionnaire follows Figure 4. A 34 item questionnaire was constructed by H. Kagami and H.O. Murakami. Questions related to : person's location at moment quake occurred ; sensation of quaking (i.e. conditions of furniture inside house) ; description of damage to buildings ; condition of ground failure. This questionnaire was also used in 1989 at the Loma Prieta earthquake site.[6]

(2) Survey Participants, Distribution, & Collection of Survey

The survey was carried out from the nine day period from september 20th to the 28th of 1990. All survey materials were collected within one month. Participants were mainly teachers from public elementary schools (and partially junior and high schools)[7].

Distribution was facilitated principally through the city regional director or the school board superintendent. Distribution to the teachers at each shool was assisted throug the principals. Collection was through reverse order, and then mailed through Japan.

Philippine elementary school is compulsory. The scale of the school is rather small but in numerous number. The number of teachers differ in urban and rural locations. Rural schools contain six to seven teachers. Urban schools contain on the average around twenty or more. Surveys were distributed to an average of ten of fifteen teachers.

11. Did you feel the earthquake ?
- 1 yes 1 [ ]
- 2 no 2 [ ]

12. How many of those around you felt the shaking ?
- 1 nobody 1 [ ]
- 2 a few 2 [ ]
- 3 many 3 [ ]
- 4 all 4 [ ]
- 5 don't know 5 [ ]

13. If anyone was sleeping, did the sleeping people awake ?
- 1 a few people woke up 1 [ ]
- 2 many woke up 2 [ ]
- 3 all woke up 3 [ ]
- 4 no one was sleeping 4 [ ]

If you did not feel the earthquake, you can finish.
Thank you very much.

14. Would you say the vibration you felt was
- 1 light 1 [ ]
- 2 moderate 2 [ ]
- 3 strong 3 [ ]
- 4 violent 4 [ ]

15. How long do you think the shaking lasted ?
- 1 sudden (less than 10 seconds) 1 [ ]
- 2 short (10 - 30 secs) 2 [ ]
- 3 long (30 - 60 secs) 3 [ ]
- 4 very long (more than 1 min) 4 [ ]

16. Were you frightened during the shaking ?
- 1 not at all 1 [ ]
- 2 a little bit 2 [ ]
- 3 quite 3 [ ]
- 4 almost panic 4 [ ]

17. What did you do during the shaking ?
- 1 stayed where I was 1 [ ]
- 2 tried to protect myself, someone else or some valuables 2 [ ]
- 3 moved to another room 3 [ ]
- 4 tried to exit building 4 [ ]
- 5 other (please specify) 5 ____________

18. If you tried to, was it difficult to move ?
- 1 easy to move 1 [ ]
- 2 difficult but possible to move 2 [ ]
- 3 couldn't move 3 [ ]
- 4 fell down 4 [ ]
- 5 didn't try to move 5 [ ]

19. Was the vibration noticed in your car ?
- 1 not in a car 1 [ ]
- 2 noticed in parked car 2 [ ]
- 3 noticed in moving car 3 [ ]
- 4 difficult to control car 4 [ ]

20. Did you see any trees, poles or parked cars move ?
- 1 none moved 1 [ ]
- 2 some moved slightly 2 [ ]
- 3 some moved violently 3 [ ]
- 4 branches broke off 4 [ ]
- 5 don't know 5 [ ]

LOMA PRIETA EARTHQUAKE INVESTIGATION PROJECT
ARCHITECTURAL INSTITUTE OF JAPAN (AIJ)

This is a survey of the Loma Prieta Earthquake of October 17, 1989. It aims to define and compare the distribution of shaking in this earthquake, and to prepare for future earthquakes. Your input is very important for the success of this project.
Please go down the pages answering the questions for this earthquake.
Thank you very much for your kind cooperation.

1. When the earthquake occurred, you were (check)
- 1 in your town 1 [ ]
- 2 somewhere else 2 [ ]

2. The address where you were located at the time of the earthquake, if known
- street ____________
- city ____________
- state,zip ____________

If not, approximate location is ____________

3. The place was
- 1 flat land 1 [ ]
- 2 on a top of hill 2 [ ]
- 3 on a slope 3 [ ]
- 4 in a valley 4 [ ]

4. You were
- 1 indoors 1 [ ]
- 2 outdoors 2 [ ]
- 3 in a vehicle 3 [ ]

5. Check your activity when the earthquake occurred
- 1 moving 1 [ ]
- 2 standing 2 [ ]
- 3 sitting 3 [ ]
- 4 lying down 4 [ ]
- 5 sleeping 5 [ ]
- 6 other (please specify) 6 ____________

6. If you were inside a building, the type of building was
- 1 house 1 [ ]
- 2 mobile home 2 [ ]
- 3 apartment 3 [ ]
- 4 office 4 [ ]
- 5 shop 5 [ ]
- 6 other (please specify) 6 ____________

7. What was the building mainly made of ?
- 1 brick or block 1 [ ]
- 2 wood 2 [ ]
- 3 concrete 3 [ ]
- 4 steel 4 [ ]
- 5 other (please specify) 5 ____________

8. How old is the building ?
- 1 built before 1935 1 [ ]
- 2 built between 1935 and 1965 2 [ ]
- 3 built between 1965 and 1975 3 [ ]
- 4 built after 1975 4 [ ]
- 5 don't know 5 [ ]

9. How many floors did the building have ? ________

10. What floor were you on ? ________

21. Did hanging objects like pictures and lamps swing ?
   1 no 1 [ ]
   2 some moved slightly 2 [ ]
   3 some moved a lot 3 [ ]
   4 some fell or were damaged 4 [ ]
   5 don't know 5 [ ]

22. What happened to windows, doors or dishes ?
   1 they rattled 1 [ ]
   2 they swung open or close 2 [ ]
   3 some dishes broke 3 [ ]
   4 some windows broke 4 [ ]
   5 don't know 5 [ ]

23. Did you see the liquids in open vessels move ?
   1 some moved a little 1 [ ]
   2 some moved a lot 2 [ ]
   3 some spilled 3 [ ]
   4 don't know 4 [ ]

24. Did shelf goods move ?
   1 none moved 1 [ ]
   2 a few shifted or overturned 2 [ ]
   3 many fell off shelves 3 [ ]
   4 all fell off shelves 4 [ ]
   5 don't know 5 [ ]

25. What happened to furniture ?
   1 furniture did not shake 1 [ ]
   2 it shook slightly 2 [ ]
   3 it moved a little 3 [ ]
   4 it moved and overturned 4 [ ]
   5 considerable damage to furniture 5 [ ]
   6 don't know 6 [ ]

Questions 26, 27 and 28 refer to your building,
OR to neighboring building if you were outdoors.

26. Damage to walls of the building
   1 none 1 [ ]
   2 fine cracks in plaster 2 [ ]
   3 pieces of plaster fell off 3 [ ]
   4 there were large and deep cracks 4 [ ]
   5 one or more walls collapsed 5 [ ]

27. Damage to foundation of the building
   1 none 1 [ ]
   2 foundation cracked 2 [ ]
   3 building moved on foundation 3 [ ]
   4 building moved off foundation 4 [ ]
   5 foundation destroyed 5 [ ]
   6 don't know 6 [ ]

28. Was there damage to chimneys, parapets and ornaments ?
   1 none 1 [ ]
   2 some cracked 2 [ ]
   3 some fell 3 [ ]
   4 most fell 4 [ ]
   5 don't know 5 [ ]

29. Was there damage to stone or brick walls,
tombstones or monuments in neighborhood ?
   1 no damage 1 [ ]
   2 small cracks 2 [ ]
   3 big cracks 3 [ ]
   4 collapses 4 [ ]
   5 don't know 5 [ ]

30. Were there ground cracks, rockfalls and
landslides in your neighborhood ?
   1 none 1 [ ]
   2 few 2 [ ]
   3 many 3 [ ]
   4 numerous 4 [ ]
   5 don't know 5 [ ]

31. Was your telephone, water, gas or electricity
interrupted after the earthquake ?
   1 no interruption 1 [ ]
   2 for a few hours 2 [ ]
   3 for a few days 3 [ ]
   4 for a week 4 [ ]
   5 longer 5 [ ]
   6 don't know 6 [ ]

32. Was you or your family injured due to the earthquake ?
   1 no 1 [ ]
   2 yes, slightly 2 [ ]
   3 treated by doctor 3 [ ]
   4 hospitalized 4 [ ]
   (what injury) ______________

33. You are
   1 male 1 [ ]
   2 female 2 [ ]

34. How old are you ? ________

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Fig. 4 Questionnaire sheet used in this survey for seismic intensity estimation made by Drs. H. Kagami and H. Murakami.

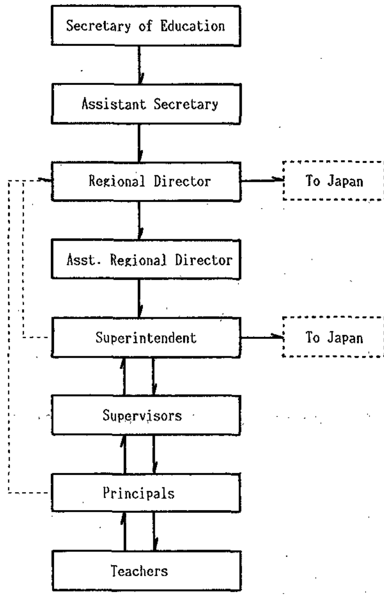


Fig. 5 Distribution and collection system of questionnaire survey method used in this survey.

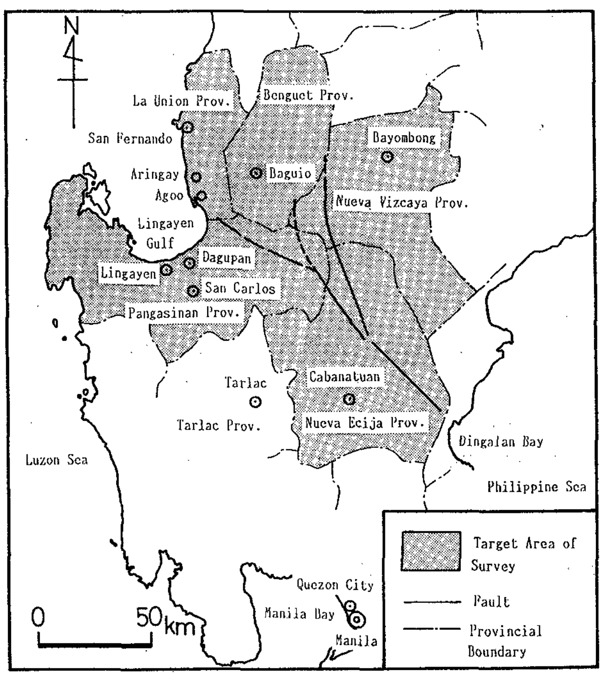


Fig. 6 Target area of this survey for the investigation of seismic intensity distribution.

Total number of surveys collected at each school is not certain at this moment.

(3) District Distribution of Surveys

The district distribution is described in Figure 6 {Benguet, La Union, Pangasinan, Nueva Ecija, Nueva Vizcaya}. These elementary schools are basically under the supervision of the school board. Although Baguio, Dagupan, San Carlos, and Cabanatuan have modified school boards, the same distribution methods were used in these four cities. In Quezon, near the capitol of Manila, surveys were distributed through the PHIVOLCS staff.

(4) Current Status of Collected Information

By using the method in section 2, we distributed 6,000 surveys from Japan, and 14,000 printed from the Philippines. The current status is reflected in Table 2. Thus far surveys

Table 2 Distribution and collection of questionnaires.

Survey Area	Number of Distributed Sheets	Collection
■ Benguet Province (Included Baguio City)	3,000	Completed
■ Pangasinan Province (Not included Dagupan and San Carlos City)	4,304	Completed
■ Nueva Ecija Province (Not included Cabanatuan City)	5,260	Completed
■ La Union Province	3,130	Completed
■ Nueva Vizcaya Province (Requested by mail)	2,000	Not yet
□ Dagupan City	400	Completed
□ San Carlos City	468	Completed
□ Cabanatuan City	705	Completed
□ Quezon City (Near Metro Manila)	200	Completed
● P.I.A	1,360	Completed
Total Number	20,827	

■ : Province
□ : City
● : Philippine Information Agency

have been collected from four provinces and five main cities, except Nueva Vizcaya. Nueva Vizcaya is located over the fault and, because of damage to the transportation network, we have been unable to distribute and collect the materials. However, the Philippine coordinators continue to help in this manner. An average of 80 percent of the materials have been collected, except Nueva Vizcaya.

4 . 2 Method of Seismic Intensity Prediction

The method used by H.O. Murakami[6] was based on the USGS research of the 1989 Loma Prieta earthquake, as well as the intensity of six other earthquakes.

(1) Intensity Coefficients (Membership Funciton)

Among the 34 survey questions there are 21 items related to intensity estimation. H. Kagami and H.O. Murakami are examining the intensity coefficients related to these questions.[8] Through the collected surveys, in order to evaluate the Modified Mercalli Intensity Scale MM, they are applying fuzzy theory for the intensity coefficient categories. As a result of this method we are more likely to obtain accurate intensity estimates. Through these procedures we are more likely to arrive at a more extended approximation of the membership rating. The membership funciton is described by a quadratic curve. Z function shows the smaller intensity and S function shows the larger intensity. Canonical P function is a broader measure. Regarding the Z and S functions, the border intensity measurements are emphasized. Table 3 shows each item category's funciton (F) and central intensity coefficients (P). The intensity breadth funcition is (W). In addition, related to question number 21, the (hanging objict) item, membership function is shown on Figure 7.

Table 3 Intensity coefficients for every question item and category.

QUESTION		CATEGORY														
No	Item	1			2			3			4			5		
		F	P	W	F	P	W	F	P	W	F	P	W	F	P	W
11	Feel quake	S	6	4	Z	1	4									
12	Others feel				P	2	3	P	5	3	S	7	3			
13	Awaken	P	2	3	P	5	3	S	8	3						
14	Vibration	P	2	3	P	5	3	P	7	3	S	9	3			
15	Duration	P	2	3	P	3	3	P	6	3	S	8	3			
16	Frighten	P	3	4	P	5	3	P	7	3	S	10	3			
17	Human bedhavior				P	6	3	P	6	3	P	8	3			
18	Moving	P	3	4	P	7	3	S	10	4	S	11	3			
19	Car vibration				S	7	4	P	8	3	S	10	3			
20	Tree, pole, car	P	3	4	P	6	2	P	8	3	S	10	3			
21	Hanging objects	P	2	3	P	4	2	P	6	3	S	9	3			
22	Windoes, dishes	P	3	3	P	6	3	S	8	3	S	10	3			
23	Liquids	P	3	3	P	6	3	S	9	4						
24	Shelf items	P	3	4	P	6	3	P	8	3	S	10	3			
25	Furniture	P	3	4	P	5	3	P	8	3	P	11	3	S	12	3
26	Walls	Z	4	3	P	7	3	P	8	3	P	10	3	S	12	3
	Wall pre 1935	Z	4	3	P	7	3	P	8	3	P	10	3	S	12	3
	Wall 35-65	Z	5	3	P	8	3	P	9	3	P	11	3	S	13	3
	Wall aft 65	Z	6	3	P	9	3	P	10	3	P	12	3	S	14	3
27	Foundation	Z	5	3	P	8	3	P	10	3	P	11	3	S	13	3
28	Chimneys	Z	5	4	P	8	3	P	10	3	S	12	3			
29	Stone, brck wall	Z	5	4	P	8	3	P	10	3	S	12	3			
30	Ground Cracks	Z	6	3	P	9	3	S	11	3	S	12	3			

F:Func tion , P:Pe ak i ntens ity , W:Wid th o f int ensi ty

ITEM	CATEGORY	FUNCTION	PEAK	WIDTH
Hanging objects	1:no swing	P	2	3
	2:slight	P	4	2
	3:a lot	P	6	3
	4:fell	S	9	3

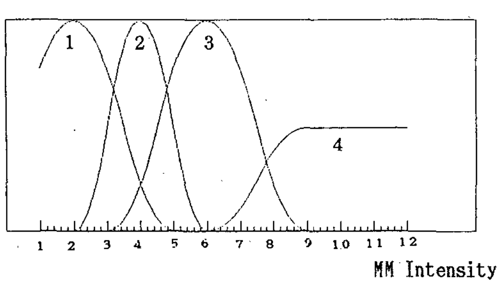
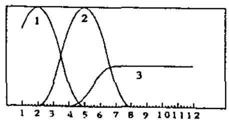
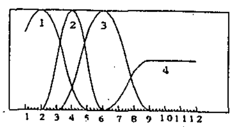


Fig. 7 Samples of membership functions of fuzzy intensity calculation method.

Table 4 List of item category and membership functions.

Item	Category	Membership Function
otehrs fell	1:few 2:many 3:all	
⋮	⋮	⋮
hanging objects	1:no swing 2:slight 3:a lot 4: fell	

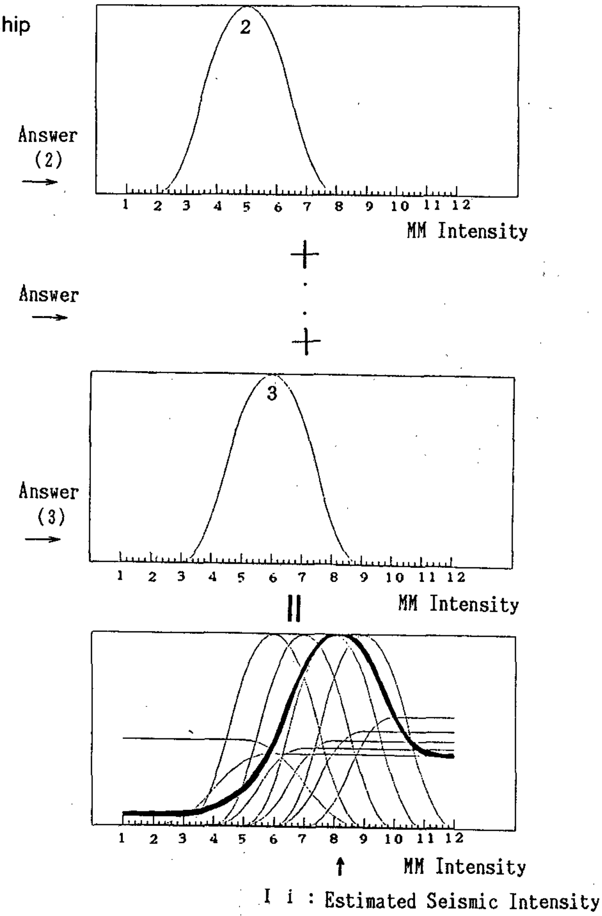


Fig. 8 Estimation of seismic intensity by fuzzy intensity calculation method.

(2) Intensity Evaluation from Questionnaire

Table 4 shows the general relationship of the questionnaire items and the categories. Each questionnaire item contains categories to be selected. The participant chooses from these categories. For each item and category, the intensity coefficients are shown, an in Figure 8. Illustrated in Figure 8 is the total addition of the distribution of the membership functions related to the item categories. So, the largest concentration number from the total distribution is the most likely intensity from the participant responses (I_i Survey Intensity).

(3) Evaluation of Representative Seismic Intensity

One method for estimating the representative seismic intensity is by finding the maximum number of the distribution using the total number of participant responses. This study used the same method[10] as that used in the Loma Prieta research. From one participant's response an estimate of the intensity was obtained. Then a group intensity method (formula 4.1) was used with the participant's intensity response.

$$\text{representative seismic intensity} = \frac{\Sigma I_i}{N} \quad \cdots \ (4.1)$$

I_i : intensity from each survey answer

N : number of participants

By this method the group seismic intensity was obtained from the school, cities, and provinces. Each was categorized.

4 . 3 Estimation of Intensity

Each city's average intensity was obtained by the method in 4.2. A map of the seismic intensity distribution was completed by district, city, and province. Participation varied according to district. The participants' maps accuracy may be in question. Despite these difficulties, it is possible to make estimates because the responses are highly concentrated in various places and number of participants is large.

(1) Intensity of Affected Cities

Table 5 Estimated seismic intensities at main cities in MM Intensity Scale.

Table 5 Estimated seismic intensities at main cities in MM Intensity Scale.

City	Estimated Intesity (MM Scale)	Number of Data
Baguio	8.8	215
Agoo	10.7	101
Aringay	9.8	117
Dagupan	8.7	396
San Carlos	7.7	463
Cabanatuan	7.8	493
Quezon City	6.5	51
Total	—	1836

Table 5 shows the estimation intensity of the affected cities (within the survey's area). To get the average intensity for each city there was sufficient data. The largest average intensity (I_{MM}) is 10.7 in Agoo. Next highest intensities were : 9.8 (Aringay) ; 8.8 (Baguio) ; 8.7 (Dagupan) ; 7.8 (Cabanatuan) ; 7.7 (San Carlos) ; 6.5 (Quezon, located north of Manila). Judging from the damage these estimates appear highly accurate. In the case of Dagupan, which experienced heavy liquefaction, further study of the seismic intensity and damage caused by liquefaction is needed.

(2) Intensity Distribution by District

Additional locations with confirmed damage are shown on the distribution map. Figure 9 shows the intensity distribution of Benguet. Attempts have been made to obtain maps from Baguio, where the heaviest damage occurred, in order to develop a separate map for Baguio. As a result, Baguio is shown in the Benguet distribution map. Figure 10 shows the Prov. of La Union's distribution. It shows Agoo's and Alingay's outstanding intensity among the others. Figure 11 shows the Prov. of Pangasinan. The eastern part shows a higher intensity than the western part, for example, Dagupan City, which had much damage from liquefaction.

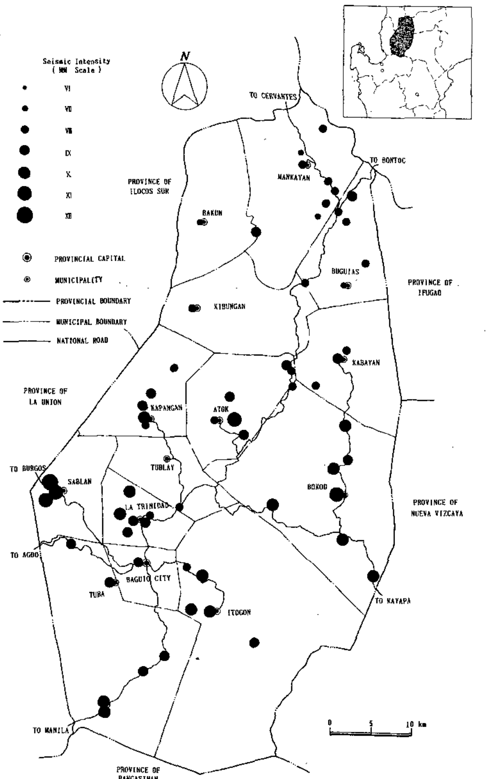


Fig. 9 Estimated seismic intensity distribution. (Benguet Province)

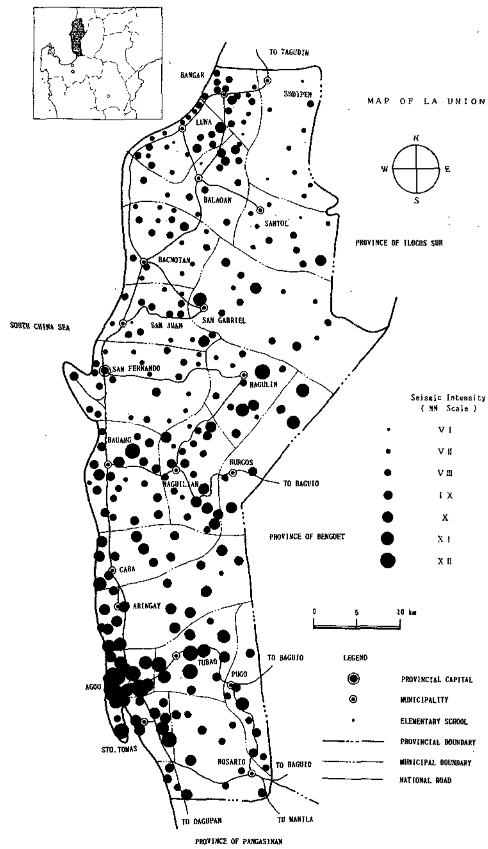


Fig. 10 Estimated seismic intensity distribution. (La Union Province)

Figure 12 shows the distribution of Nueva Ecija, located above the epicenter. According to this figure, the largest intensity is located along the fault near the epicenter. Cabanatuan is the largest city in this province, and the entire intensity distribution is reported in Figure 13. In Cabanatuan we succeeded in obtaining a separate distribution map which confirmed the public schools' locations. For Dagupan and San Carlos separate distribution maps were also completed.

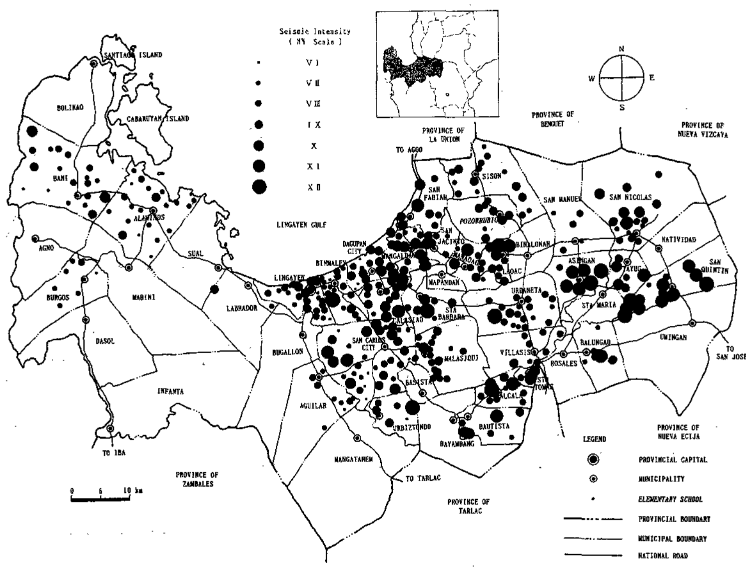


Fig. 11 Estimated seismic intensity distribution (Pangasinan Province)

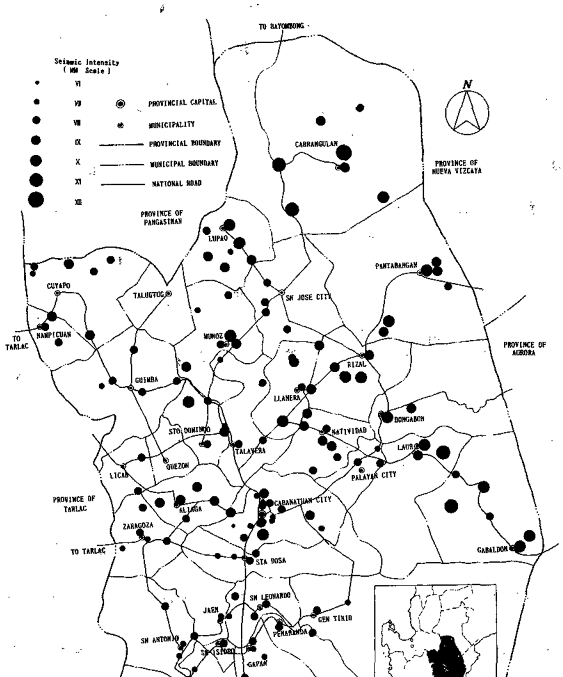


Fig. 12 Estimated seismic intensity distribution (Nueva Ecija Province)

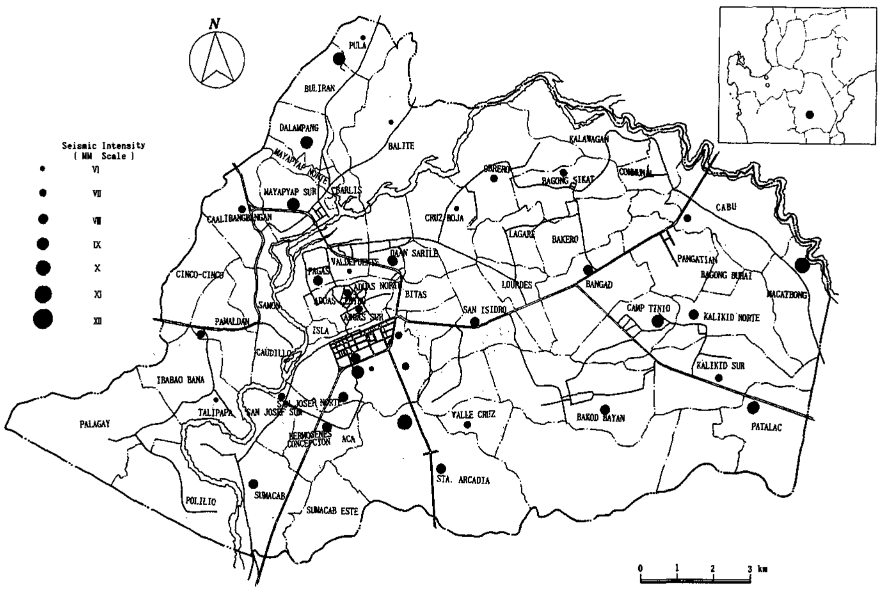


Fig. 13 Estimated seismic intensity distribution (Cabanatuan City)

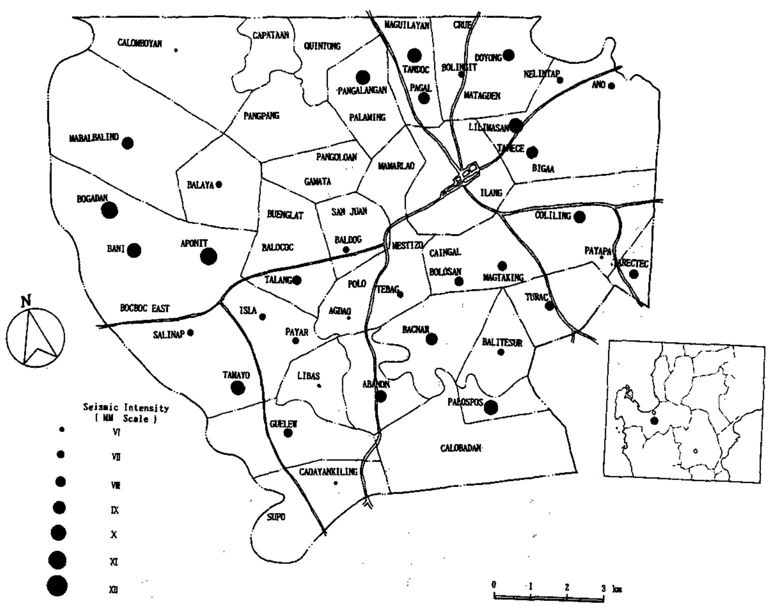


Fig. 14 Estimated seismic intensity distribution (San Carlos City)

These two cities have large populations and their own school boards. Besides these distribution maps, a general distribution map is shown in Figure 16. This figure also corresponds with the individual figures; as noted in Figure 16, Baguio, Agoo and eastern Pangasinan and areas along the fault are estimated relatively high seismic intensity (area highlighted). Bagio and Agoo are located on the west side of the northwestern end of the main fault.

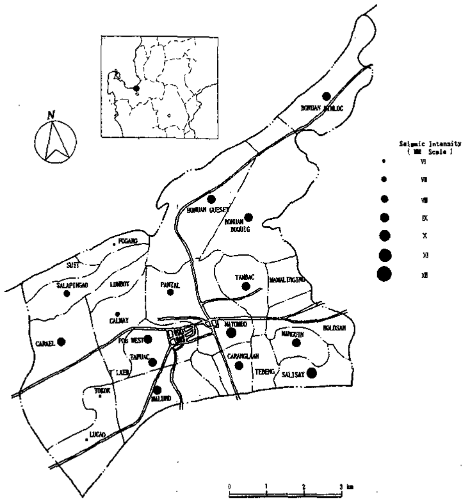


Fig. 15 Estimated seismic intensity distribution (Dagupan City)

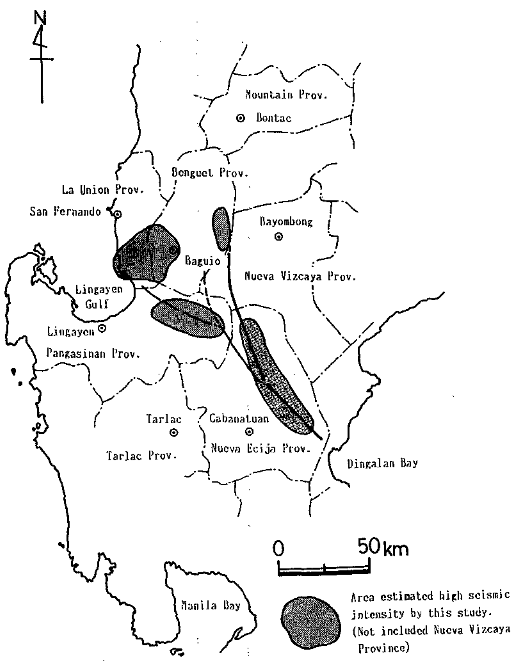


Fig. 16 Distribution of areas estimated relatively high seismic intensity by this survey. (This map didn'n include the analytical results of Nueva Vizcaya Province.)

(3) Evaluation of Seismic Intensity & District Comparisons

After examining the results, it is possible to obtain an estimation of average intensity {range of 6.5 to approx. 9.0} for the following five cities (using MM Seismic Intensity Scale) : Baguio, Dagupan, San Carlos, Cabanatuan, Quezon. This intensity difference will be compared with an analysis of responses from the intensity evaluation questionnaire. The result will help examine characteristics of seismic motion. Considering this point a comparison among the five cities related to the seismic intensity has been completed.

Table 6 List of some question item and category related to seismic intensity estimation.

Question		Choices of answer	
I-14	Would you say the vibration you felt was ?	0 1 2 3 4	no answer light moderate strong violent
I-15	How long do you think the shaking lasted ?	0 1 2 3 4	no answer sudden (less than 10 seconds) short (10 - 30 secs) long (30 - 60 secs) very long (more than 1 min)
I-18	If you tried to, was it difficult to move ?	0 1 2 3 4 5	no answer easy to move difficult but possible to move couldn't move fell down didn't try to move
I-24	Did shelf goods move ?	0 1 2 3 4 5	no answer none moved a few shifted or overturned many fell off shelves all fell off shelves don't know
I-25	What happened to furniture ?	0 1 2 3 4 5 6	no answer furniture did not shake it shock slightly it moved a little it moved and overturned considerable damage to furniture don't know
I-27	Was there damage to foundation of the building ?	0 1 2 3 4 5 6	no answer none foundation cracked building moved on foundation building moved off foundation foundation destroyed don't know
I-29	Was there damage to stone or brick walls, tombstones or monuments in neighborhood ?	0 1 2 3 4 5	no answer no damage small cracks big cracks collapses don't know

The survey consists of 34 questions, 20 of which focus on intensity evaluation ; and from which intensity coefficients are obtained. Participants select each question item response category. A few written responses are also requested. Among the 20 items (Table 6), 7 of them (I − 14, 15, 18, 24, 25, 27, 29) related to intensity evaluation, are compared among the respondents from the five cities. The content of the 7 items focus on reported sensations related to the seismic motion (I − 14, 15, 18), and furniture damage (I − 24, 25) and building damage (I − 27, 28). In Figure 17, the responses to these 7 items are illustrated. The total number of respondents (N) varied. Baguio (Is = 8.8), N = 215 ; Dagupan (Is = 8.7), N = 396 ; San Carlos (Is = 7.7), N = 463 ; Cabanatuan (Is = 7.8), N = 493 ; Quezon (Is = 6.5), N = 51. The horizonal line in Figure 17 shows item category numbers. The vertical line shows participant percentages against the total number.

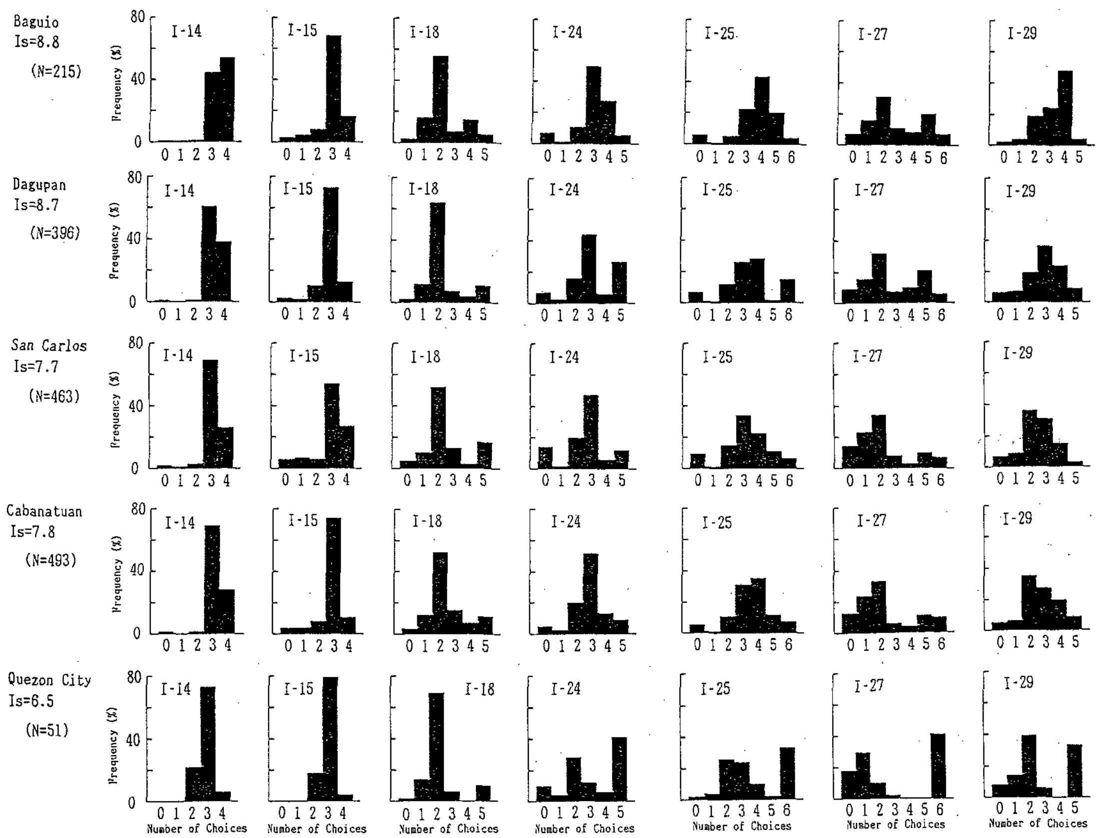


Fig. 17 Distribution of choices related to the items and categories of each question summarized at main cities.

The MM intensity among the five cities ranges from 6.5 to 8.8. From items 14, 15, and 18, Baguio participants responded with a rating of 4 (violent) to item 14 (4 is the highest rating). In items 15 and 18 there is no significant difference in response. Each district experienced a long, shaking motion. It was difficult, but possible to move around.

Items 24 and 25 pertain to furniture damage. The estimated intensity shows a relatively noticeable difference. Among the three cities Dagupan, San Carlos, and Cabanatuan respondents reported similar damage. But, Baguio with the highest estimated intensity and Quezon the lowest, showed a significant difference when compare with one another. Related to building damage, item 29 revealed a significant difference in a comparison of city responses.

5. SUMMARY

Using MM intensity prediciton among the affected cities we have compiled maps of intensity distribution. As previously noted, these are provisional. Further study may result in some change. Through this research, the Philippine earthquake's intensity distribution has been clarified. The intensity distribution corresponds with the damage distribution. The result provides important data for assessing the intensity of seismic motion. The earthquake's epicentric process influenced this intensity distribution, as analyzed through this survey.

To be completed are : examination of the intensity evaluation method, damage distribution comparison, comparison of more accurate maps with geological and topographical maps etc., and further study of localized and broad intensity distribution maps.

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Key Words (キー・ワード)

Seismic intensity (震度), Questionnaire survey (アンケート調査), Seismic microzoning map (サイスミックマイクロゾーニングマップ), Modified Mercalli intensity scale (修正メリカリ震度階), Modified Rossi-Forel intensity scale (修正ロッシフォーレル震度階)

フィリピン・ルソン島地震の高密度震度分布調査

1990年7月16日午後4時26分(現地時間)にフィリピン・ルソン島の中央部に発生したフィリピン地震(M＝7.8)は，内陸部に発生した最大級の地震であり，延長約120km，水平平均ずれ量約5.0mに及ぶ左横ずれ断層が出現した。震度地は，首都マニラの北北東約110kmのDigdig断層上で，震度の深さは約25kmとされている。

本地震において，多数の建物が被災し約2000名の死者と3500名の負傷者が発生し，全壊建物約22000棟，被災者約160万人に及び被害が発生した。この地震による被害は，地震断層に沿った広範囲の地域に発生したが，被害が比較的集中的に発生した地域は，震央近傍の地域より，むしろ上記地震断層の北西方向の末端部の西側に位置している地域に多数の被害建物が認められた。また，Lingayen湾に面した沿岸地域の沖積軟弱地盤地帯においては，顕著な液状化現象が発生し，多数の構造物に被害が認められた。しかし，残念ながら本地震の被災地域における強震観測記録は得られていない。

本研究の目的は，アンケートによる震度推定法を用いて本地震の震源域を中心とする広い範囲の地域における震度(MM震度)を可能な限り高密度に推定し，強震記録に代わる情報のひとつとして各地の地震動の強さとその分布状況を推定することである。また，被害地域といえども，ごく狭い地域でさえ被害程度に大きな差を生じることは過去の地震において確認され，今回の地震においてもまた同様の傾向がみられた。そこで，可能な限り高密度の震度分布を推定し，被害分布などともにいわゆるサイミックマイクロゾーニングマップを作成することを最終的な目的としている。本報告は，これまでに分析ができた各地の震度分布の結果を示したのである。

その結果，調査地域内の主要都市の推定震度では，La Union州のAgoo町が最も大きく平均震度(MM震度)で10.7となり，次いでAringay町で9.8，Baguio市で8.8となる。以下，Dagupan市で8.7，Cabanatuan市で7.8，San Carlos市で7.7，首都Manilaの北側に隣接するQuezon市で6.5と推定された。また，各州や主要都市における震度分布も明かとなっている。

本調査により，1990年フィリピン地震の震源域における震度分布がほぼ明かとなり，震度分布は被害分布とよく対応し，地震動の強さを推測する上で，重要な情報を提供するものと考えられる。