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A DENSE AND PRECISION SURVEY OF SEISMIC INTENSITY AS AN EFFECTIVE TOOL IN ENGINEERING SEISMOLOGY

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SUMMARY

This paper briefly reports the dense and precision determination of seismic intensity by a questionnaire method advanced in both survey scheme and subsequent data processing and its application to engineering seismology. Following to a short description of the survey procedure, a few examples of the application to drawing minute isoseismal maps, to exploring seismic source and path characteristics, and further to elucidating microzoning characteristics in urban area are given by the intensity data from a case study for the 1981 Off-Urakawa, Hokkaido, Japan earthquake. The obtained results are found well satisfactory through various comparisons with instrumental and other data.

INTRODUCTION

The best way for determining the seismic severity is doubtlessly to use the instrumental data by a strong motion seismometer. But it is not so easy as expected. In Japan it is rare that we have 10 or more strong motion records good for analysis even in a large earthquake. Yet its areal distribution is inhomogeneous as most of them are installed in major cities, along national railways, and in important structures. Because of this Japan is too far to be ideal in strong motion data availability for evaluating spatial distribution of seismic severity in an earthquake. The other countries than Japan seem to be in the similar or rather worse condition. If this is the present situation, there is a reason why we consider that an urgent task is to introduce a good substitute for the instrumental data. One of our long-term studies is to provide a better substitute of measuring the seismic severity by developing a field survey technique of "Seismic intensity".

This paper describes first the procedure of seismic intensity survey and then its application to engineering seismological problems, while demonstrating the significance of dense and qualified seismic intensity data.

DENSE SURVEY OF SEISMIC INTENSITY

There are several ways for determining the seismic intensity. A field determination by inspection of damaged structures is the most popular technique and most isoseismals are drawn using such seismic intensity data. But, judging from the fact that for an earthquake we often encounter plural numbers of isoseismals drawn by different reseachers, this method has some risk of giving rather subjective results. Another one which is also popular is a mail survey by a postal card with several to 10 questions. The dominant merit in this method is its simplicity. But, this method is also insufficient in the accuracy of the measured intensity. Therefore all the intensity data in this manner are considered merely auxiliary material. In Japan the seismic intensities are formally reported by the Japan Meteorological Agency(JMA) for every felt-earthquake. But, they are insufficient as for the basic data of the succeeding studies because of their sparse density and of the low accuracy in the determination. A more objective and

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high-precision intensity determination is desired.

What we have wanted to develop in Japan is essentially a questionnaire method. But, the developed one is considerably different in both survey scheme and subsequent data processing. In the affected areas by an earthquake there are numbers of residents, if its magnitude is somewhat large. We regard such people as the earthquake-observers whose individual responses are more or less fuzzy but statistically processed responses in a certain bounded area are qualified. Then by introducing an intensive survey we can expect that the conventional questionnaire method will be renewed from both in density and precision of seismic intensity determination.

In a class of intensity V according to the JMA scale, for example, there is no description about any structural damages, in spite that intensity VI brings collapsed house of 10-30%. This suggests that the JMA scale is too rough to be applied to advanced damage analysis. The acceleration corresponding to the intensity V is considered 80-250 gals and it is to wide to be condensed in a class from engineering point. One of our major aims in this study is to improve the accuracy of intensity determination from one to two significant figures.

Questionnaire

Prepared questionnaire contains 34 items of questions. Several items are for asking the respondent's physical situation of residential house, house plan, floor number etc and the non-physical situation in which state he or she encountered a shock. The items directly related to seismic intensity are around 20 in number from people's perception to forced behavior under shaking, and to damage to structure and nonstructure elements and also to physical deformation of indoor and nearby environs. All items in the questionnaire are made in reference with the texts in the JMA intensity scale. The answers to be checked are arranged in categoric manner and in ascending order of seismic severity(See Appendix). Special attention paid is to prepare duplicate questions in a certain range of intensity to improve the accuracy of respondents. Arrangement of order of item-categoric questions, number of categories for a question, and, layout and format of the questionnaire etc are carefully decided in consideration of respondent's convenience. A set of questionnaire is composed of 4 pages by A-4 size sheet.

Survey scheme and processing

The actual procedure differs depending upon the immediate objective of survey. If we want to disclose the general pattern of isoseismals covering all the affected areas, the areal size to be surveyed should be in concordance with earthquake magnitude. If a shallow earthquake with magnitude around 7 occurs in and around Japan, several hundreds of municipalities (of city, town or village unit) are generally included in the felt area. Therefore, 5,000-10,000 questionnaires are necessary for the delivery to those residents via local governmental offices so as to get 20-50 collections from each municipality. In case we have a special objective of elucidating near-distant isoseismals a more dense survey is carried out for the areas including epicenter. If the survey is concentrated in one city, it gives considerable data to assess microzoning characteristics. In such variety of ways we have been conducting for more than 20 earthquakes in Japan.

The collected questionnaires are analysed to get raw intensities first, as one intensity by one questionnaire, and then by use of several tens of raw intensity data in a unit area, statistically processed to improve its accuracy towards two significant figures. Our questionnaire intensity I_Q expressed with two digits is, after rounded off, reduced to the JMA intensity I_{JMA} with a single effective digit.

Verifications of our questionnaire survey were made from various points of view. Fig. 1 is an example. The upper two maps show the topographical features drawn from collected questionnaires and the lowest map does actual one in a surveyed city. This comparison proves that people's answers are well conceivable. Another example listed below is a numerical comparison among I_Q, I_{JMA} and maximum ground accelerations measured in a specific site;

I_Q	I_Q(rounded off)	I_{JMA}	Acc (gal)
4.5	5	V	213
3.9	4	V	88
3.8	4	V	90.

From this we know that our intensities are much more sensitive to delicate changes of the seismic severity at a site(and that two JMA intensities of V in lower lines had better revised as IV).

EXAMPLES OF APPLICATION

On March 21, 1982 an earthquake with M = 7.1 occurred off Urakawa, Hokkaido district in northern most Japan and suffered significant amount of damage in several towns along the Pacific coast and a few inland cities. The maximum intensity by the JMA was VI at Urakawa, but there was no area where intensity V was reported. The second maximum intensity of IV was reported at several cities in considerable epicentral distances. Such an unusual event seems mostly due to that in Hokkaido district there are sparse JMA stations at which the intensities are determined. For the purpose to overcome such contradiction and to draw precise isoseismal maps including epicentral region, a survey was carried out distributing 6,500 questionnaires to all of 212 municipalities in Hokkaido.

On the other hand in Sapporo, the capital city, with a population over one million, various damages of grounds and dwellings and of interruption of life line systems were observed differently from place to place, although the formally reported intensity was a single value of IV. This suggests that a solitary observation for such big city is too inappropriate and give no useful information to the subsequent areal damage analysis. Therefore, we performed a dense questionnaire survey for elucidating the microzoning characteristics of Sapporo city.

Isoseismal map

The delivery of 6,500 questionnaires was made in regard with population as 100 for a city with 100,000 population or higher, 50 for the other cities and 25 for a town or a village, and we got 86.5% answers. Fig. 2 illustrates 0.25 increment-isoseismal maps drawn using the obtained intensities by municipalities. The actual drawing was made automatically by Ohta and Kagami's technique[1]. The observed isoseismals are somewhat irregular than circular. Contour lines seem extended in E-W direction , but contracted in N-S direction. This is a common character of isoseismals due to earthquakes in Hokkaido district. To know more detail about this peculiarity, the deviation from the standard intensity attenuation with distances was deduced and its anomaly map was drawn in Fig. 3 and compared with the so-called Bouguer anomaly map compiled by Hagiwara[2]. As is seen in this figure we find a remarkable correlation between two maps. It is evident that, in the region where intensity anomaly is positive, deep seated soft soils deposit widely, and, in its negative region, geologically old or volcanic rocks distribute. This clearly shows that the obtained isoseismal map reflects well the regionality in seismic wave propagation.

Epicentral region

A dense questionnaire survey was also performed in several towns locating Pacific coastal line in the epicentral region. Fig. 4 summarizes observed and calculated intensity distributions, together with the other physical data. The upper most curve shows relative ground deformation before and after this earthquake. The second one is PGA(peak ground acceleration) distribution curve estimated by Kobayashi et al. The lowest ones are our calculation and observation. The calculated intensities are based upon the empirical equation proposed by us previously[3]. All the distributions cited here are in remarkable agreement. A comparison of the ground deformation curve with that of observed intensity tells that the occurrence of dominant ground failure is limited within the region where the intensity is equal to or higher than the lower bound of VI, which is in good agreement with the description in the JMA intensity scale.

Urban area

Similar but more dense survey was performed in Sapporo city distributing 10,000 questionnaires so as to cover whole the residential area, and got 83 % answers. Fig. 5 shows the histogram through which one can see the observed intensities spreads from II to V in the JMA scale, though the average intensity of 3.8 is in good agreement with that reported by the JMA Sapporo station. Areal distribution of intensities are shown in Fig.6 together with site plots where considerable damage occurred.

Next, we examined a physical reason behind such microzoning characteristics. Since Sapporo city is in an epicentral distance range of (145 ± 15)km, distance dependency seems small. Source and path effects are also less influential because, in this distance, source finiteness can be out of consideration and all the paths to Sapporo are approximately identical. If these are true, only the probable reason would be the site effect due to surface soils. Fig. 7 illustrates a line-up of histograms of intensity deviation(δ I) from the average value by surface soil types. The upper 4 histograms are for alluvial soils, which indicate rather large intensities, and the remainder ones are mostly for older soils and rock sites. The soil layer thickness is effective up to 10m but after that it seems saturated.

Based upon this analysis we can develop an empirical equation to estimate seismic intensities in Sapporo city. The intensity at a given site, I_i, is written as

$$I_i = f(M, \Delta) + \left[\begin{array}{ll} 0.256 & \text{silt} \\ 0.182 & \text{peat} \\ 0.050 & \text{volcanic ash} \\ 0.040 & \text{sandy silt} \\ -0.051 & \text{sandy and clayey silt} \\ -0.156 & \text{river deposit} \\ -0.278 & \text{gravel} \\ -0.396 & \text{andesite(weathered)} \\ -0.406 & \text{talus} \end{array} \right] + 0.04\, H_i$$

where

$$f(M, \Delta) = 2M - 4.601 \log \Delta - 0.00166 \Delta - 0.32 \quad \text{by Kawasumi[4],}$$

and M the JMA magnitude, the epicentral distance in km, H the thickness of surface soil in m.

CONCLUDING REMARKS

Through a variety of seismic intensity surveys by means of an advanced questionnaire method we found that dense and qualified intensities are rather easily obtained and such intensity data are well applied for succeeding analyses on seismic source and path characteristics and for comparative study with damage and other data. Since this questionnaire method is simple and systematic enough to be performed with no much special technique, we would like to say in conclusion that it should have wider application capability to any other countries than Japan. For more examples of the application, refer Ohta[5].

There are at least two major problems to be solved relating to "seismic intensity". One is to continue this series of studies to widen its application capability in engineering seismology as well as in earthquake engineering. The other important problem is to develop a way of understanding physical background of seismic intensity in the manner far precise than is approximated simply as a function of the peak ground acceleration only.

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APPENDIX: Examples of item-categories in the questionnaire(originally in Japanese)

* Where were you when the earthquake occurred?
  1. indoors 2. outdoors 3. in a vehicle 4. or________
* What were you doing there?
  1. moving 2. at rest 3. sleeping
* What was the material of the building(house) you were in?
  1. rubble stone 2. cut stone 3. brick 4. wooden 5. reinforced concrete
* Who felt the vibration around you?
  1. nobody around 2. a few 3. many 4. most 5. all
* How did the windows and dishes move?
  1. windows and dishes rattle 2. few dishes and glassware break 3. doors and windows swing, open and slam back 4. most break down
* How did furniture shake?
  1. shakes slightly 2. moves a little 3. moves and overturns 4. considerable damage
* Was there any damage to the building?
  1. none 2. fine cracks in plaster 3. small cracks in walls, fall of pieces of plaster 4. large and deep cracks 5. collapse
* Was the building leaned?
  1. no 2. slightly 3. seriously 4. almost collapse
* Were cracks in ground or on roads observed near around?
  1. no cracks 2. few small cracks 3. large cracks 4. ground considerably distorted
* Were rockfalls and landslides observed near around?
  1. none 2. few 3. many 4. numerous

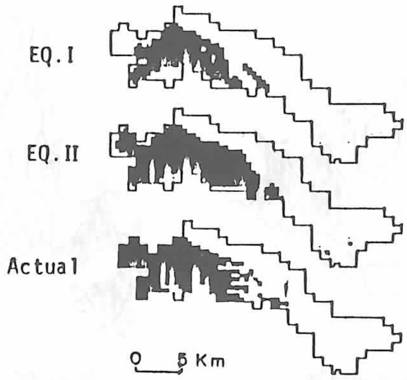

Fig. 1 Comparison of deduced and actual topography.

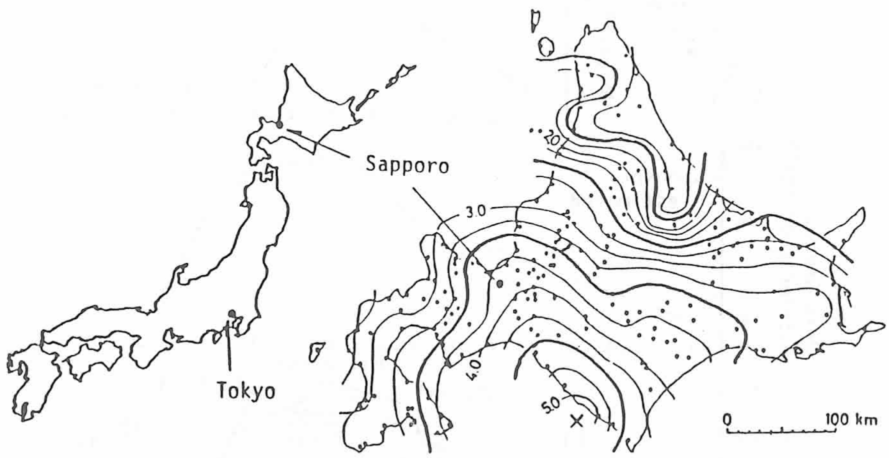

Fig. 2 Obtained isoseismal map.

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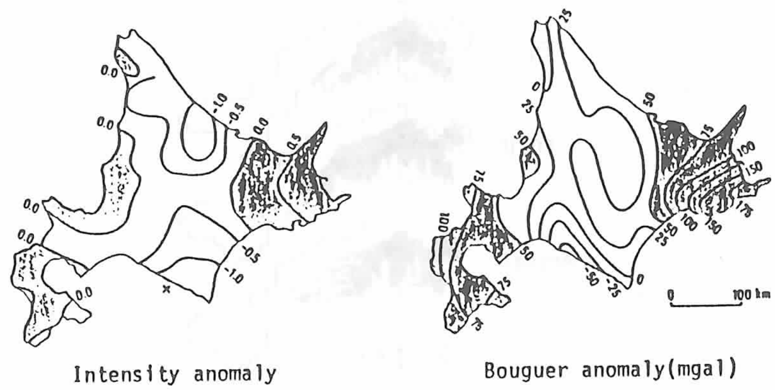

Fig. 3 Comparison between intensity and Bouguer anomalies.

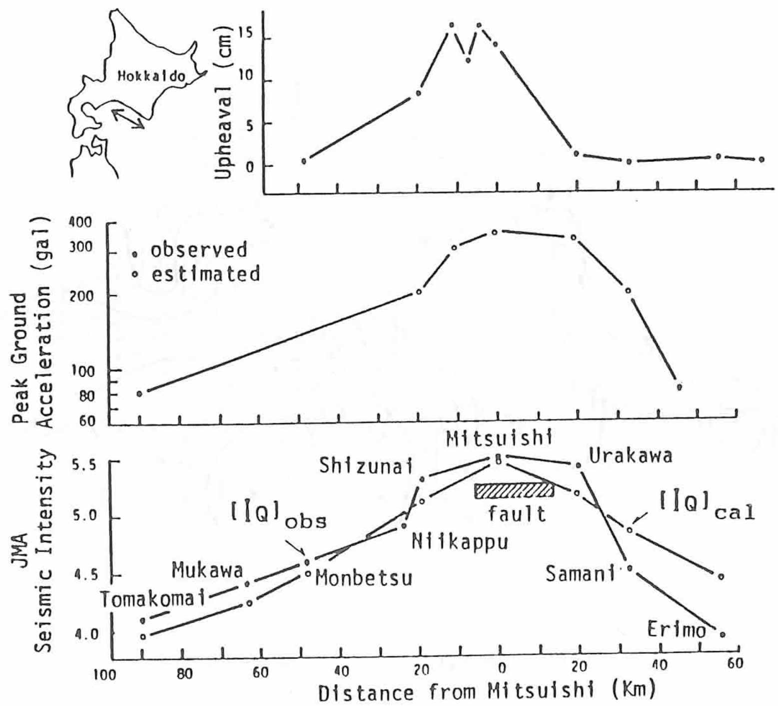

Fig. 4 Comparison of intensity with other physical data.

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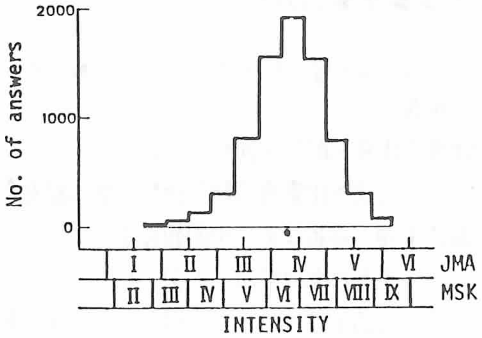

Fig. 5 Histogram of intensities obtained in Sapporo city.

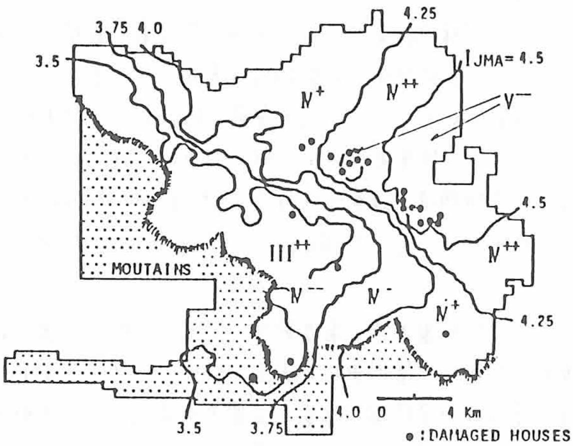

Fig. 6 Intensity microzoning map in Sapporo city.

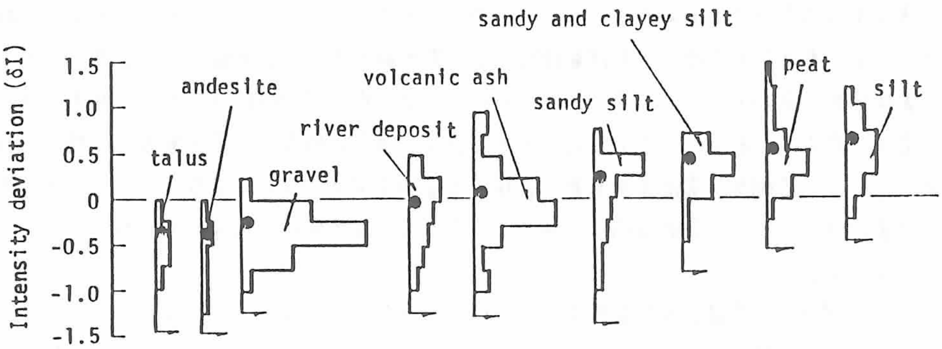

Fig. 7 Histograms of intensity deviation by soil types.

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