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Dense Survey of Seismic Intensity for Wider Application to Earthquake and Engineering Problems

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Abstract

Motivated by a belief that qualified seismic intensity data should have a wider application capability in engineering seismology and earthquake engineering, we have been continuing a series of investigations, based essentially upon a questionnaire method advanced in both of survey scheme and subsequent data processing. In this paper we demonstrate a few applications to drawing minute isoseismal maps, to exploring seismic source and path characteristics, and further to elucidate microzoning characteristics in urban and rural areas. The exemplified incidences are 1982 Off-Urakawa, 1983 Central Japan Sea, 1981 Corinthos, 1984 Morgan Hill and 1986 Hollister earthquakes. The obtained results are well examined through various comparisons with instrumental and other data.

1. Introduction

For more than a decade we have been conducting a dense survey on seismic intensity for almost all the moderate-to-large earthquakes occurring in and around Japan and also have been applying it to foreign earthquakes. We had developed the method by means of questionnaire in order to estimate seismic intensities precisely and densely[1]. The major reasons are as follows. The officially announced seismic intensities by JMA (Japan Meteorological Agency) have serious demerits in that its determination is made in a limited number as 2-3 locations per prefectural unit with the average area of 10,000 km^2 and that its accuracy is rather low due to the summary determination. Therefore the announced intensities are insufficient to be basic data for succeeding studies in seismology and engineering. High-precision and dense survey has long been desired in this respect.

In this paper, major subjects covered and results obtained through this series of studies are summarized in its applications to engineering seismological and earthquake engineering problems, demonstrating the significance of dense and qualified seismic intensity data.

Department of Architectural Engineering

2. 1982 Off-Urakawa Earthquake

On March 21, 1982 a large earthquake with M = 7.1 occurred off Urakawa, Hokkaido district in northern most Japan and caused a significant amount of damage in several town-ships along the Pacific coast and a few inland cities. Although the maximum intensity by the JMA was VI at Urakawa, no continuation to V was reported at any affected areas. We performed dense questionnaire surveys for this earthquake with special objectives of obtaining a precise isoseismal map, elucidating intensity distribution along the coastal line passing through epicentral area, and characterizing microzoning Sapporo city.

2.1. Isoseismal map

The delivery of 6,325 questionnaires was made in relation of 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 received 86.5% answers. Figure 1 illustrates 0.25 increment-isoseismal maps drawn by use of obtained intensities by municipalities. The actual drawing was made automatically by Ohta and Kagami's technique[2]. The observed isoseismals are somewhat irregular than circular. Contour lines seem to be 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 in detail about this peculiarity, the deviation from the standard intensity attenuation with distances was deduced and its anomaly map was drawn as is shown in Figure 2 and compared with the so-called Bouguer anomaly map compiled by Hagiwara[3]. As is seen in this figure we find a significant correlation between two maps. It is evident that in a region where intensity anomaly is positive deep seated soft soils deposit widely and in its negative region geologically old or volcanic rocks are distributed. This clearly shows that the obtained isoseismal map reflects well the regionality in seismic wave propagation.

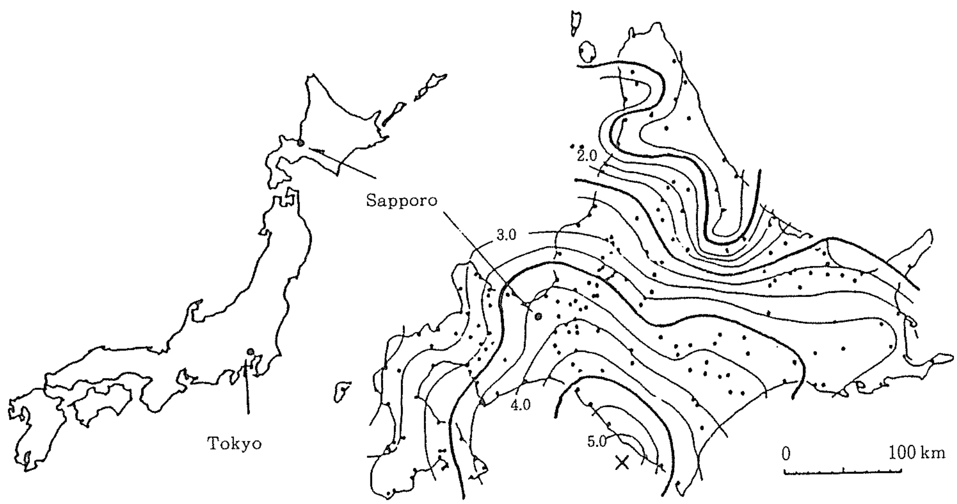

Fig. 1 Obtained isoseismal map of 1982 Off Urakawa earthquake.

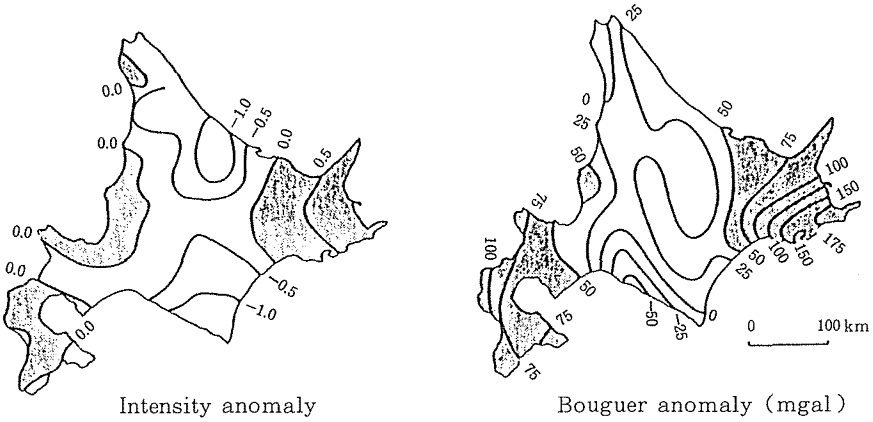

Fig. 2 Comparison between intensity (1982 Off Urakawa eq.) and Bouguer anomalies.

2.2. Epicentral region

A dense questionnaire survey was performed in several towns located on the Pacific coastal line in epicentral region. Figure 3 summarizes observed and calculated intensity distributions, together with other physical data. The upper most curve shows relative ground deformation between this earthquake. The second one is PGA(peak ground acceleration) distribution curve derived by Kobayashi et al[4]. The lowest ones are from our calculations

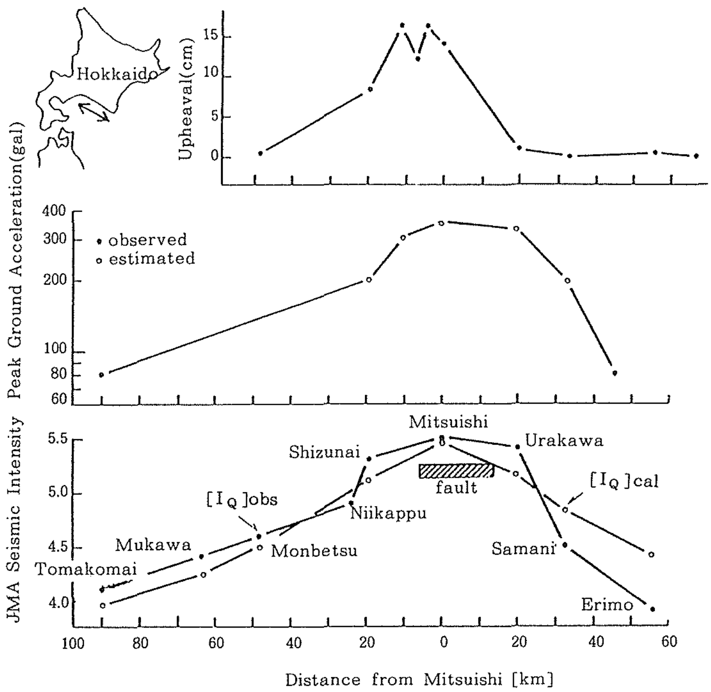

Fig. 3 Comparison of intensity (1982 Off Urakawa eq.) with other physical data.

and observations. The calculated intensities are based upon the empirical equation proposed by us[5]. *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 failures is limited within the region where the intensity is equal to or higher than the lower bound of VI.

2.3. Urban area

A similar but more dense survey was performed in Sapporo city distributing 10,000 questionnaires so as to cover the whole residential area, and we obtained 83 % answers. Figure 4 shows the histogram through which one can see that the observed intensities spread from II to V in JMA scale, although the average intensity of 3.8 is in good agreement with that by JMA Sapporo station. Areal distribution of intensities are shown in Figure 5 together with site plots where considerable damages occurred. Thus obtained microzoning characteristic reflects well the seismic severity distribution due to this earthquake.

Next, we examined the physical reason of such microzoning characteristics. Since Sapporo city is in an epicentral distance range of (145 ± 15)km, the distance effect seems small. Source and path effects are also less influential because, at this distance, source

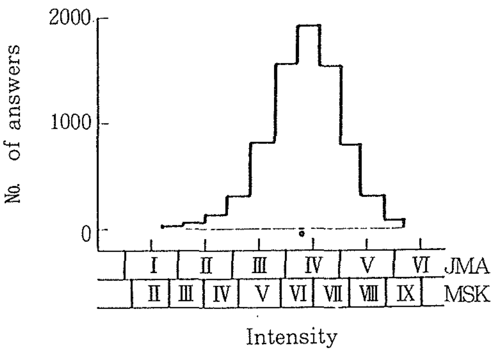

Fig. 4 *Histogram of intensities obtained in* Sapporo city (1982 Off Urakawa eq.).

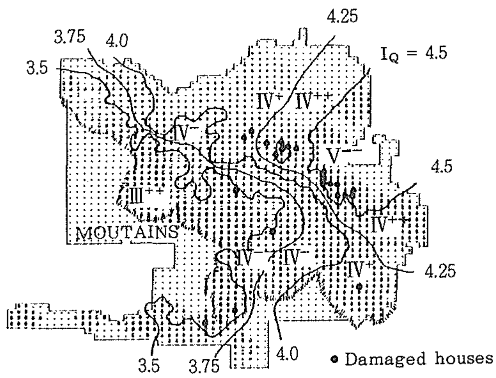

Fig. 5 *Intensity microzonig map in Sapporo city* (1982 Off Urakawa eq.).

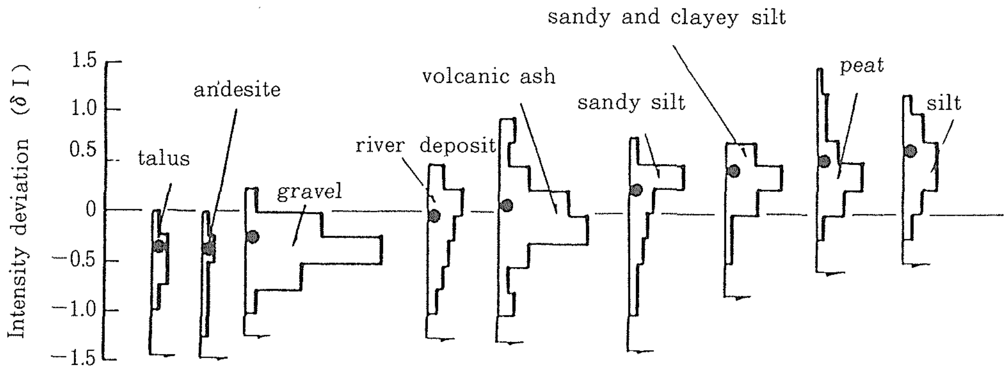

Fig. 6 Histograms of intensity deviation by soil types in Sapporo city (1982 Off Urakawa eq.) .

finiteness can be out of consideration and all of the paths to Sapporo are approximately identical. If these are true, only the physical possibility of such spatial intensity distribution should be explored in the so-called site effect due to surface soils. Figure 6 illustrates a line-up of histograms of intensity deviation (δI) from the average value by surface soil types. The right side 4 histograms are for alluvial soils, which indicates rather large intensities, and the remainder are mostly for older soils and rock sites. The soil layer thickness is effective up to 10m but after that it seems to be saturated.

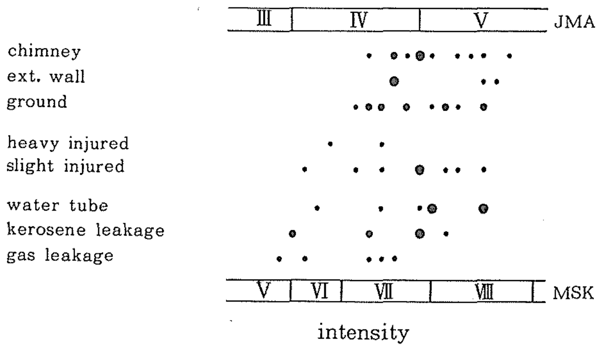

Fig. 7 Relation between intensity and various disasters in Sapporo city (1982 Off Urakawa eq.).

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

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

where

$$f(M,\Delta) = 2M - 4.601 \cdot \log\Delta - 0.00166\Delta - 0.32 \quad \text{(Kawasumi[6])}$$

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

Figure 7 summarizes various disasters observed in this city in relation with seismic intensities.

3. 1983 Central Japan Sea Earthquake

A great earthquake occurred on May 26, 1983 and brought serious damages to northern districts in mainland Japan. Because of its large magnitude of 7.7, the affected areas were so wide covering Hokkaido, Tohoku and Kanto districts of nearly 10 prefectures. For this earthquake a dense survey was performed similarly to the 1982 Off-Urakawa earthquake, including 435 municipalities. The total number of questionnaires delivered exceeds well 10, 000, by which almost all the areas with intensity of III and higher were investigated. The answers arrived to a total of about 80%. By use of these data several analyses were conducted.

3.1. Isoseismal pattern

The actual intensity determination was made at 403 unit areas. Although the maximum intensity by JMA is reported as V at 3 stations, we could reveal that there are several areas where it reached VI. The isoseismal map drawn with 0.25 increment is illustrated in Figure 8. From this we find several significant features. One is that the area with intensity V and higher spreads widely in NS direction than in EW direction. This seems due to configurational characteristics of the earthquake fault. The other contours have also the similar tendency of extending in a NS direction. And this tendency is rather common to most isoseismal maps for shallow earthquakes occurring in the northern part of Japan.

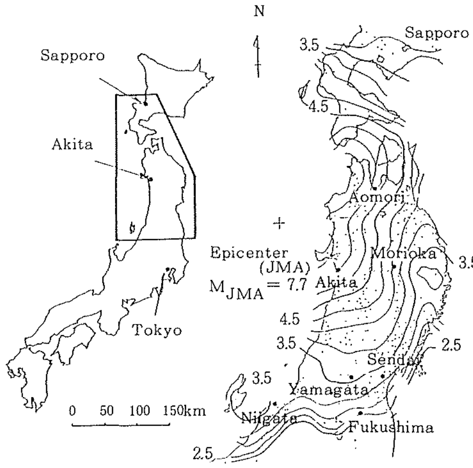

Fig. 8 Obtained isoseismal map of 1983 Central Japan Sea earthquake.

3.2. Source and path effects

The N-S directionally extended isoseismal contours in Figure 8 can not be explained by a simple attenuation equation assuming a point source and seems to reflect well the finiteness of the seismic source. We have already proposed an empirical equation appropriate for near-distance intensity distribution enclosing a seismic source area (Ohta[5]). Let us apply the same equation to this earthquake. According to the equation, the intensity at any point on the ground is expressed as

$$I=C_1 \log D^k \int^L \int^w \frac{1}{F(R^{-P})} d\zeta \cdot d\eta ,$$

where D is the average resultant slip measured by the coordinate system (ζ,η) on the fault surface, k is the coefficient related to the slip contribution upon intensity, and p is the coefficient related to the attenuation due to the distance, and the appropriate values are empirically derived for k and p as 0.25 and 2-3 respectively. Here, we perform the following examinations. Namely, through the numerical comparison of calculated and observed intensities at near-distances we attempted to determine the optimum configurational solutions in terms of fault length and strike direction. The ranges we examined are for fault length L from 40 to 200km and for strike direction from N30° W to N30° E, assuming that the fault width is known as W=40km and the dip angle as 30° E. The actual calculations were done in such a way as to evaluate the correlation between the observed and the calculated intensities in ranges higher than III. Figure 9 illustrates contours of the thus obtained correlation coefficient. From this we know that the optimum values are L=120km and N20° E, though the probable values for fault length and strike direction are of a somewhat wider range. These values are in fairly good agreement with those derived from instrumental data. This clearly tells that the obtained isoseismals well reflect the source finiteness and configurational characteristics.

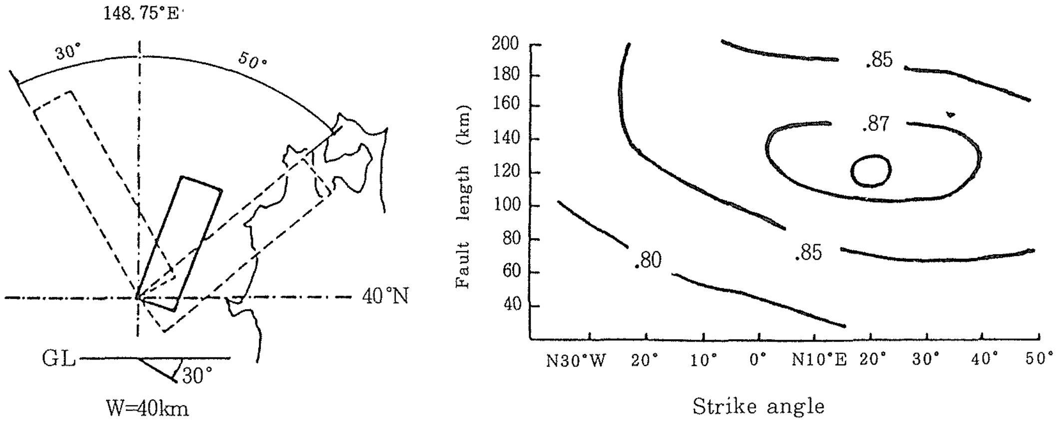

Fig. 9 Estimation of fault length and strike direction (1983 Central Japan Sea eq.) .

3.3. Local site effect

A case study in a town located along the Japan Sea coastal line with a population of 10,000, a whole survey for all the families was performed and compared damage and other data in order to elucidate local changes of seismic effect. Figure 10 illustrates the observed intensities by 18 sub-areas in comparison with structural damage rate and periods necessary for recovery of daily life and for restoration of dwelling. We understand that all of them in

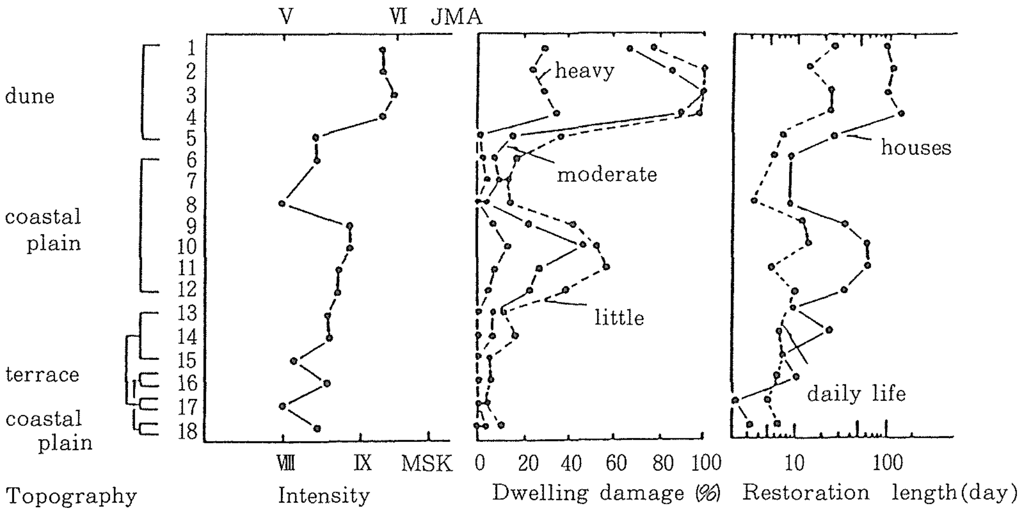

Fig. 10 Comparison of intensity with damage and aftermath in Wakami town, Akita prefecture (1983 Central Japan Sea eq.) .

sub-areal distribution are in dominant correlation and therefore the seismic severity measured in terms of seismic intensity is the most fundamental factor on direct and indirect earthquake disasters. If we compare this intensity change with local geological data, we find that the sub-area with highest intensity is composed of the latest sand dunes and the second highest areas are of alluvial soils and in the areas with surface soil older than alluvium the intensities are clearly low.

4. 1981 Corinthos, Central Greece Earthquake

In 1981, February 24th a shallow earthquake of magnitude Ms=6.7 occurred in the eastern part of Corinthian Gulf in Central Greece, which is accompanied by a largest aftershock in February 25th of magnitude Ms=6.4, causing widespread damage to an area larger than 1,500 km^2. The focal depths of the two events were about 15 km under the sea, nearby the tiny Alkionides island[7] (Figure 11).

The questionnaire survey was planned in order to evaluate the seismic intensity and also elucidate the direct to indirect damages. After considering the affected region, the capital city of Corinthos having 45,000 population was chosen as one of the survey sites. The city lies on the eastern end of the Gulf on alluvial deposits where damages were concentrated. The other survey site was sought in a rural area so that a comparative study versus urbanized area could be performed. The village of Perahora (population 2,200) was selected where the most extensive damages were seen. The village had a total of 470 houses and lies on mountainous firm ground.

The questionnaire form was prepared translated from Japanese to Greek and some more questions inquiring about social impacts were added. The first part of questionnaire sheet, with 29 items, is arranged so as to correspond to the definition of MSK intensity scale. The second part, with 47 items, asks about various aspects of earthquake damage as well as, the restoration process, economical impact on household income and some mental effects on people. The survey was taken place in July 1985 and by directly interviewing the local people with questionnaire sheets. We obtained 137 and 66 effective answers by Corinthos

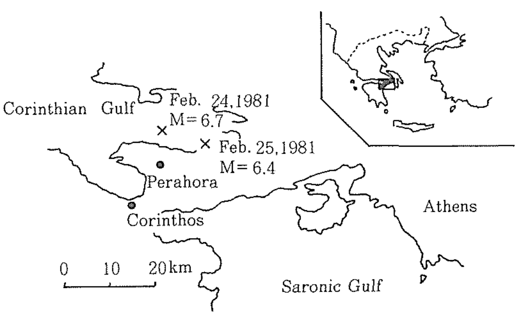

Fig. 11 Epicenters and surveyed sites for 1981 Corinthos, Central Greece earthquake.

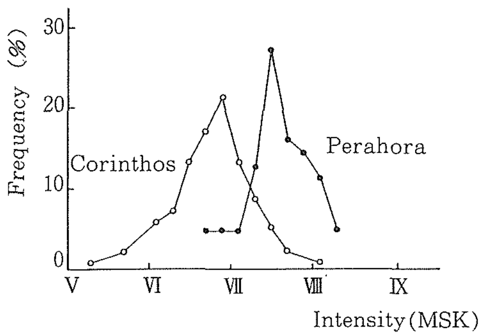

Fig. 12 Histograms of obtained intensities for Corinthos and Perahola (1981 Corinthos eq.).

and Perahora inhabitants.

In Corinthos we had intensities ranging from 5.6 to 8.1, with an average intensity of 6. 8 when rounded out is the equivalent to the intensity VII in MSK scale. In Perahora we had intensities ranging from 6.6 to 8.4, with an average of 7.6 which rounded out is equivalent to VIII. Thus, a clear difference between the intensities in the two sites was obtained as shown in Figure 12.

Through the survey the following social effects are also revealed. The whole economic activities of the region were decreased and are not yet completely recovered at the time of answering the questionaires. In Corinthos more than 25% of the families living in R. C. framed buildings, have changed dwelling place to seek for a safer residence although the damage to their buildings was not so heavy. In Perahora, where 70% of the houses become uninhabitable, extensive reconstruction took place and at the time of this survey was in its final stages. But still many of the families live in shelter houses of very low standards because they cannot afford the reconstruction cost.

5. 1984 Morgan Hill and 1986 Hollister Earthquake of California, USA.

In order to examine the effectiveness of questionnaire survey and intensity estimates in MM scale, a trial survey was planned in California, USA and the following conditions were considered in the choice of target earthquakes. a) The earthquake is recent so that people can remember its effects and damages correctly. b) The affected area is properly populated and several towns are distributed. c) Instrumental records were obtained. Thus the 1984 Morgan Hill earthquake ($M_L=6.2$) in California was chosen. While preparing for the survey, the Hollister earthquake ($M_L=5.5$) occurred on January 26, 1986 in the same region, about 65 km apart. We decided to add another set of the same questions for the second earthquake for further comparison. Table 1 shows the attributes of the two earthquakes[8].

Table 1 Studied earthquakes

	1984 Morgan Hill	1986 Hollister
Data	Apr. 24, Tue.	Jan. 26, Sun.
Time	1 : 15 PM	11 : 20 AM
Magnitude (M_L)	6.2	5.5
Max intensity (MM)	VIII : Limited area VII : Morgan Hill	VII : Cienega Valley VI : Hollister
Strong motion record (PGA)	1.29g : Coyote Dam 0.46g : Gilroy 0.31g : Hollister	0.31g : Hollister

We contacted county boards of education and school districts asking cooperation to distribute and collect questionnaires through schools to parents. We chose 16 public school

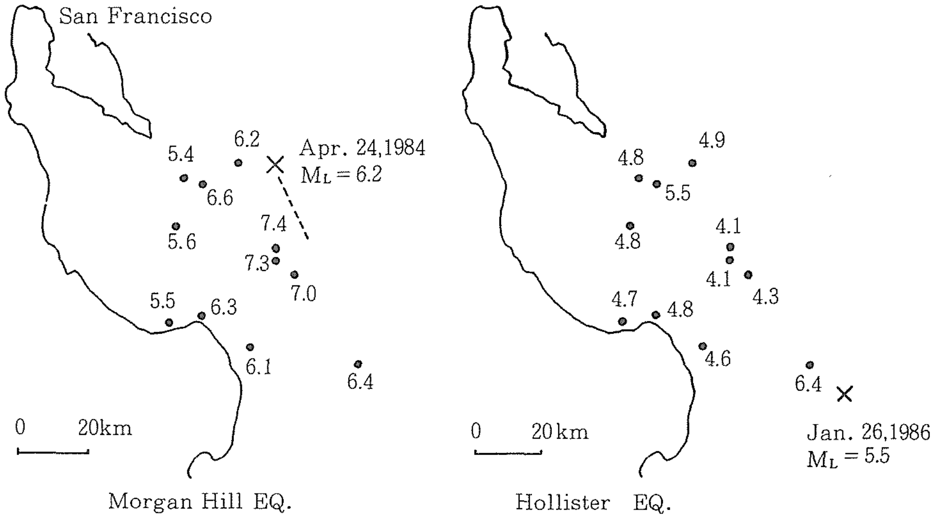

Fig. 13 Obtained intensities for two earthquakes in California.

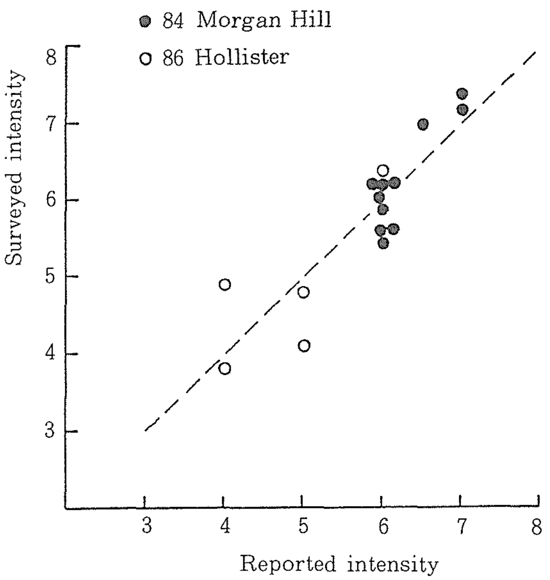

Fig. 14 Comparison of obtained intensities with reported ones for the two earthquakes in California.

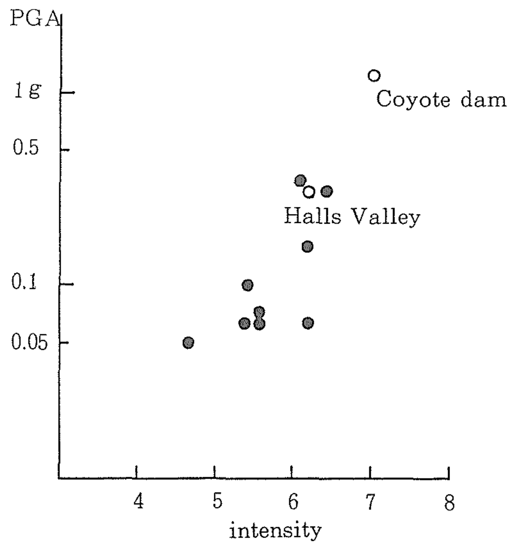

Fig. 15 Comparison of obtained intensities with PGA of strong motion records for two earthquakes in California.

in Santa Clara county, 5 in Santa Cruz county, 3 in Monterey county and 2 in San Benito county within the MM 6 isoseismal of Morgan Hill earthquake. Hundreds questionnaires were mailed to each of 26 schools in late April, 1986. The maps in Figure 13 show the surveyed area and the epicenters.

Calculated intensities and observed intensities are compared in Figure 14. Observed intensities of Morgan Hill earthquake are from Toppozada and those of the Hollister event are assigned based on USGS earthquake report and news articles. Calculated intensities agree very well with the observation by a seismologist through the range of 4 to 7.

CDMG[9] and USGC[10] have an extensive network of strong motion instruments in the surveyed area. Calculated intensity is compared with PGA in Figure 15. Good correlation between intensities and PGAs is found.

6. Concluding Remarks

Through this series of studies for developing seismic intensity survey by means of questionnaire method we found that dense and qualified intensities are rather easily obtained and such intensity data are well applied for advanced analysis on the seismic source and path characteristics and for comparative study of damage and other data. In conclusion we should like to say that, since this questionnaire method is simple and sufficintly systematic to be performed with no much special technique, it should have wider application capability to any other countries than Japan.

Acknowledgment

The authors wish to acknowledge that these surveys have been accomplished with the cooperation of hundreds of thousands of people who deigned to answer this questionnaire. The survey in Greece was performed by cooperation of Mr. Antonios Pononis, Foreign Student of Hokkaido University, and they express their thanks to him.

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