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ARTICLE

Extraction of Ground Characteristics Based on Questionnaire Seismic Intensity and the Applicability to Seismic Microzonation

Masanori MIYAZAKI* • Takashi AKIYOSHI** • Shozo SHIRINASHIHAMA***

Abstract

This paper proposes a simple method to estimate quantitatively ground characteristics of surface layers based on the seismic intensity map by questionnaire survey after an earthquake's occurrence and also discusses its applicability to seismic microzonation. The questionnaire surveys have been performed for three moderate earthquakes which occured around Kumamoto City. This paper shows that the subtraction of seismic intensity by the empirical attenuation formula from local seismic intensities by questionnaire surveys reflect the differences of local ground characteristics of surface soft layers. Finally, the seismic microzoning map in Kumamoto City was shown as an application of the proposed method.

Key words : Seismic intensity, Attenuation formula, Questionnaire survey, Seismic microzonation, Identification of geological characteristics of surface layers, Moderate earthquakes

1. Introduction

Immediately after an earthquake occurrence, the JMA seismic intensity scale I_{JMA} which is usually shown in Roman numerals is publicized by the Japan Meteorological Agency at every station. This seismic intensity informations are on no more than a few sites in each area. Ohta *et al.* [1),2)] has recently developed a more reliable seismic intensity scale by questionnaire survey which is shown in Arabic numerals and called "questionnaire seismic intensity I_Q". This I_Q is presented as two significant figures and gives a particular seismic intensity at each local site.

In 1972, Kawasaki City, Kanagawa Pref., the questionnaire survey method by Ohta *et al.* was applied to three earthquakes. Eventually, the stability and reliability of Ohta's method was verified through results of the analyes [1)]. After that, seismic intensity distributions for about 50 domestic and foreign earthquakes have been decided through this method using 200,000 questionnaires [3)]. These questionnaire

* Department of Architectural Engineering, Kyushu Tokai University
** Department of Civil and Environmental Engineering, Kumamoto University
*** Technical Research Institute Tekken-Kensetsu Corporation

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survey analyses have been extended to across wide range; preparation of detailed seismic intensity distribution maps, intensity attenuation with hypocentral distance [4], comparisons and reviews between questionnaire seismic intensities and earthquake damages [5], human psychology and behavior during earthquake [6], relations between seismic intensities and surface ground characteristics [7), 8), 9), 10] and so forth.

Many of these memoir are case studies of each earthquake. In this study, using seismic intensity distribution maps by questionnaire survey for the three sample earthquakes, a general examination of the local differences of seismic intensity in an area was conducted. The authors defined the subtraction(;seismic intensity deviation dI) of seismic intensity I_A by empirical attenuation formula from questionnaire seismic intensity I_Q[9]. This seismic intensity deviation dI is expected to be a statistical parameter to represent or extract local ground characteristics. It would be shown in the analysis that strong cross-correlation between this deviation dI and stiffness or thickness of surface soft layers exists and this deviation dI is a quantitative index for local amplification of shaking at each site to surface ground structure. Finally, it is concluded that the proposed seismic intensity deviation dI is suitable and applicable to highly accurate seismic microzonation since it expresses several distinct factors for local ground characteristics.

2. Seismic Intensity Distribution by Questionnaire Survey

In the anlyses, three moderate-class earthquakes which occurred in the vicinity of Kumamoto City were used:

(1) the main shock of earthquake swarms located north off-Aso Somma (33°00'N. 131°08'E. M=6.1 H=0 km : hereafter called "ANE") on Jan. 23, 1975,

(2) the main shock of earthquake swarms located north of Kumamoto Pref. (32°54'N. 130°43'E. M=5.2 H=10km : hereafter called "KNE") on June 28, 1977,

(3) the earthquake near Yatushiro Sea (32°27.6'N. 130°27.7'E. M=5.0 H=13km : hereafter called "YSE") on July 28, 1986.

For the three sample earthquakes, questionnaire surveys were carried out in cooperation with staffs in Kumamoto Pref. Police and Municipal Offices, etc. Seismic parameters for these three earthquakes and the number of distribution and collection of questionnaires are shown in Fig. 1 and Table 1, respectively.

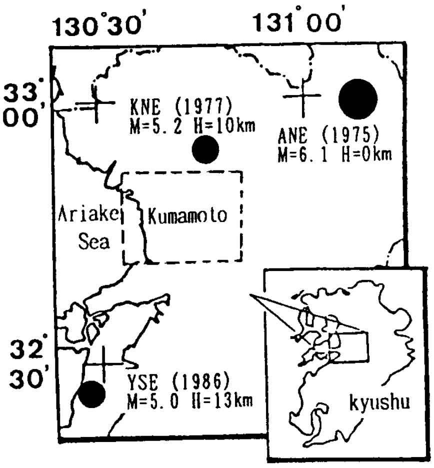

Fig.1 Locations of epicenter of the three sample earthquakes. Dotted line shows the analyzed area.

Table 1 Seismic parameters and distribution or collection of questionnaires for the three sample earthquakes.

Earth. list	Scale (M)	Depth (km)	I_{JMA}	Questionnaires	
				Distributed	Collected
ANE	6.1	0	IV	500	493(98.6)
KNE	5.2	10	IV	112	112(100)
YSE	5.0	13	III	2300	1954(85.0)
	‹determined by JMA›				‹sheets (%)›

A prepared questionnaire contains 34 items of questions. Several items are for asking the respondent's physical situation of address, residental house, house plan, floor number, etc. and the non-physical situation in which state he or she encountered a shock. Others (around 20 items) are directly related to seismic intensity which are estimated from people's perception of forced behavior under shaking, and damage of structural and nonstructural elements and also physical deformation of indoor and nearby environs. All items in this questionnaire are made in reference with the texts in JMA intensity scale. The collected questionnaires are analyzed to get raw intensities first, as one intensity by one questionnaire sheet, and then by use of several raw intensity data in a unit area seismic intensity I_Q at this site is prepared for later statistical processing. This I_Q is accurate to two significant figures and is equal to the I_{JMA} rounded to one decimal place.

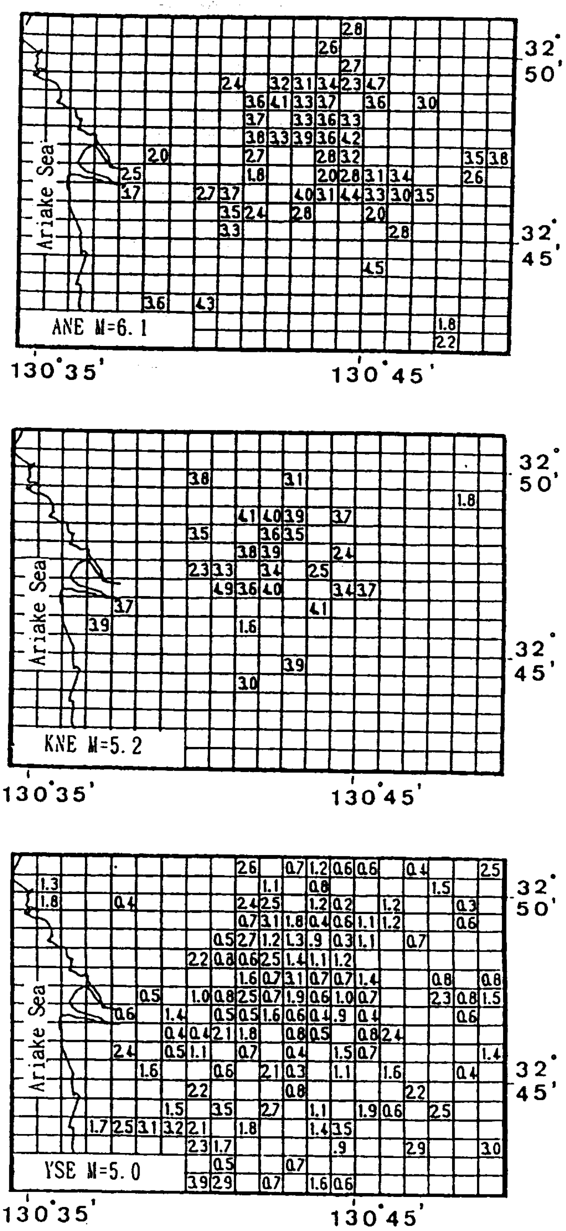

Fig.2 Seismic intensity distribution maps in and around Kumamoto City based on questionnaire surveys for the three moderate earthquakes.

Table 2 The number of collected questionnaires versus meshes and topography.

Earth.	Total	1	2	3	①	②	③	④	A	B	C
ANE	60	27	10	23	5	10	28	17			
KNE	31	15	1	15	5	8	13	5			
YSE	145	22	32	91	5	51	52	37			
SMKM	154	30	17	107	9	51	53	41	88	53	13
survey area	(moutanious) 351(urban area)				41	92	96	68 54			

Remark (number of meshes)

1, 2, 3 : seismic intensity calculated from one, two and more than three questionnaires respectively

① : reclaimed land after 1588

② : reclaimed land before 1587

③ : alluvial fan

④ : diluvial upland and moutenious etc.

A, B, C : seismic intensity calculated from questionnaire for one, two and three sample earthquake respectively

SMKM : seismic-deviation-microzoning map in and around Kumamoto City

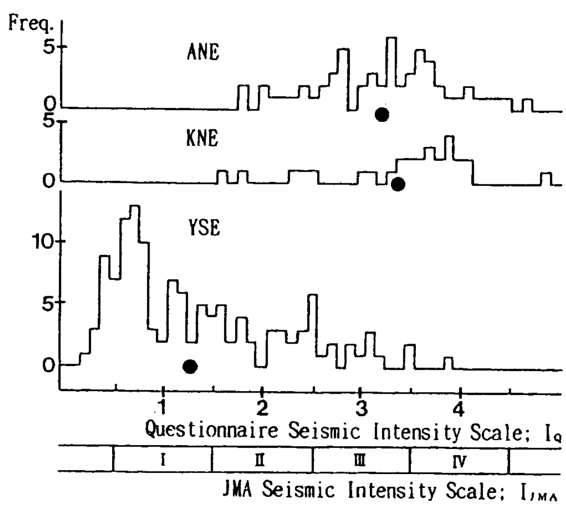

Fig.3 Frequency diagrams of seismic intensity I_Q for the three sample earthquakes. ● marks indicate the averaged value

According to statistical processing, questionnaire seismic intensities I_Q are assigned on the third standard mesh (normally called the 1-km^2 mesh diagrams, accurately being equivalent to 0.5' in latitudinal width and 0.75' in longitudinal width). Then seismic intensity distribution maps are obtained as Fig. 2. The number of collected questionnaire sheets is shown versus meshes and topography, etc. in Table 2. Frequency diagrams of seismic intensity I_Q for each of the three earthquakes are shown in Fig. 3. In the case of YSE, seismic intensities I_Q mostly appear in the range less than 2.0. Goto [11] and Miyazaki [12] have confirmed the validity of this excessively small seismic intensity.

From mutual comparison of these seismic intensity distribution maps, proper adjustments were made for removing apparent inconsistency regarding earthquake magnitude and hypocentral distance. Also the geographical non-uniformity between the coastal area of Ariake Sea and diluvial plateau area, etc. or the difference of local ground characteristics even in adjacent areas were adjusted slightly in the analyses. The causes of such unconformity in seismic intensity distribution will be reviewed in following chapters.

3. Ground Characteristics of Surface Layers at Kumamoto City and Attenuation of Seismic Intensity with Hypocentral Distance

When ground surface layers in Kumamoto Pref. are investigated, the stratigraphy and distribution of the Aso pyroclastic flow deposit over 4 times [13), 14] are of importance. In addition, the history and distribution of reclamation works along the shoreline of Ariake Sea have been clearly recorded and stored in old documents [15]. The reclamation works are divided into five periods; the first stage is before 1587, the second in former part of the feudal age (in 1588-1763), the third in later part of the feudal age (in 1764-1868), the forth and fifth in Meiji age (in 1869-1912) and Taisho age (in 1913-1926). Refering to the results of analyses by the Ministry of Construction [16], Watanabe [17] and Miyazaki [18] together with these records, an outline of topography and geology near Kumamoto City can be shown as in Fig. 4.

Since ANE was located far from Kumamoto City and the other two sample earthquakes KNE and YSE were of moderate scale, authors adopted the point source determined by the JMA. Hypocentral distance r is defined as the distance from focus to central point in a mesh. Questionnaire seismic intensities I_Q are plotted versus epicentral distance Δ as in Fig. 5. Seismic intensity by Ohta's attenuation formula [19] (hereafter refered as "Ohta's formula seismic intesity I_A") was computed and plotted as a solid line in the diagram.

Ohta's intensity attenuation formula is

$$I_A(r) = \left\{\frac{5.5}{I(R)}\right\}^{\frac{2}{1+0.5\times 10^{(0.3/R)}}} \times I(r) \ : \ \text{[Ohta's formula]} \tag{1}$$

where $I(r) = 2M - 10.2 + 2\log(r_0/r) - 0.01668(r - r_0)$: [Kawasumi's formula]

$R = 10^{(0.5M-2.12)}$

and M : the JMA magnitude, r : hypocentral distance (km), r_0 : r at epicentral distance of 100km (km), R : limit radius to disastrous zone which is determined by magnitude (km).

4. Statistical Evaluation of Seismic Intensity Deviation Based on the Ground Characteristics of Surface Layers

The questionnaire seismic intensities I_Q observed on the ground surface at each site generally appear as the synthesized result of source process (scale factors of earthquake; fault plane and area, rupture velocity, etc.), propagation path process (geometrical attenuation with distance, viscosity damping in the path medium, etc.) and local ground characteristics (topography, geology, soils, layer thickness, density, etc. of the ground). If these factors can be treated separately, a predicting method of seismic

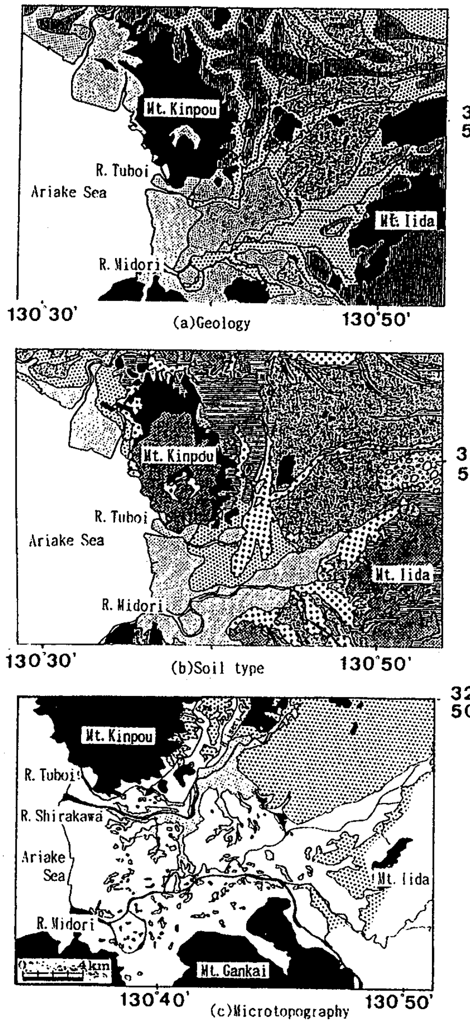

Fig.4 Ground surface maps in and around Kumamoto City. (the classification pattern due to *Table 3*)

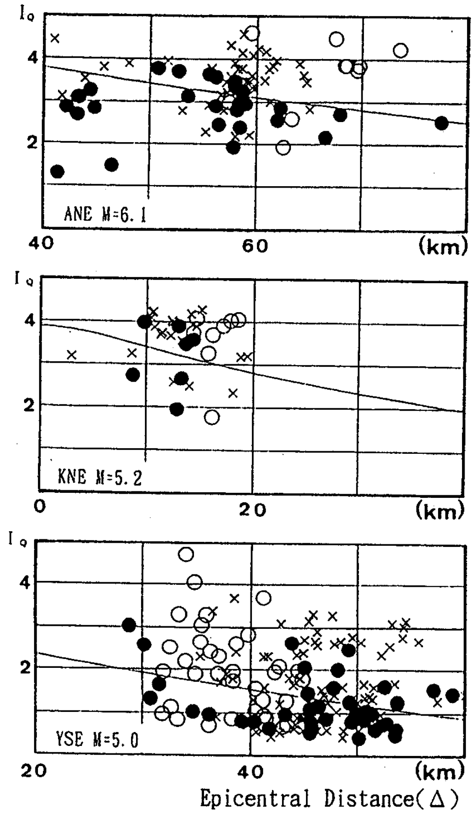

Fig.5 Attenuation of questionnaire seismic intensity I_Q with epicentral distance Δ for the three moderate earthquakes.
○ marks indicate questionnaire seismic intensity at the soft ground group
× marks indicate those at slightly soft ground group
● marks indecate those at hard ground group
The solid line is an attenuation intensityby Ohta's formula in JMA magnitude scale.

intensity at the sites for future earthquakes will be easily developed.

In this study, three sample earthquakes are used for seismic intensity analysis in same area. It is very important to take account of the fault plane and areas or its dislocations from a mechanical viewpoint. Some studies on seismic intensity distribution have tried comprehensive explanation by considering fault effect and refering to Ohta *et al* [20]. These would be available for ground motion near the field of seismic center of a remarkable earthquake of M>7. However, in this study, the magnitude M=6.1, M=5.2 and M=5.0 of sample earthquakes are not so remarkable, and analyzed areas are out of source region (hypocentral distance r=10 ～ 70 km). Therefore it is assumed that the seismic intensity distribution in this study would not be affected by the source process.

Now, let "*E*" denote the input due to source and path process, "*G*" the system due to surface layers and "*I*" the output gain response at the ground surface. Then the response "*I*" can be expressed as a system function of *E* and *G.i.e.*, $I=f(E,G)$. Thus the characteristic value of system can be determined in the form of the deviation or quotient of output and input. As shown in Ohta's attenuation formula (1), I_A is modified from Kawasumi's formula and show the trend of general attenuation of I_{JMA} with

Table 3 Classification of surface layers in and around Kumamoto City and analyzed extents of shaking(m_{wg},m_{ws} and m_{wm})

(a)Geology

Subsurface geology		Mark	Structure material	m_{wg}	Remarks
Alluvial sediment	Reclaimed land(after 1588)		Silt, Clay, Sand etc.	0.62	Soft
	Reclaimed land (before 1587)		Silt, Clay, Sand etc.	0.17	↑
	Fan		Sand, gravel etc.	0.08	
Terrace gravel bed			Loam + Gravel etc.	-0.28	
Aso-pyroclastic flow deposit			Loam, Silt + Tuff etc.	-0.46	↓
Pre-Aso volcanic rock			Loam + Andesite etc.	-0.77	Hard

(b)Soil type

Classified soil type		Mark	Grading or solidity	m_{ws}	Remarks
Alluvial sediment	Clay		small	0.59	soil type available to 40m in depth
	Sand		↕	0.32	
	Sand gravel		large	0.13	
Plateau or Foot volcano	Loam + Gravel		low	-0.29	up to basement
	Loam + Tuff		↕	-0.40	
	Loam + Andesite		high	-0.56	

(c)Microtopography

Topography	Mark	Surface geology	m_{wm}	Remarks
Back swamp		Mud (fine)	0.21	
Natural levee		Sand (coarse)	0.15	
Plateau		Pyroclastic flow deposit	-0.02	
Mountainous		Andesite, Rock etc.	-0.48	

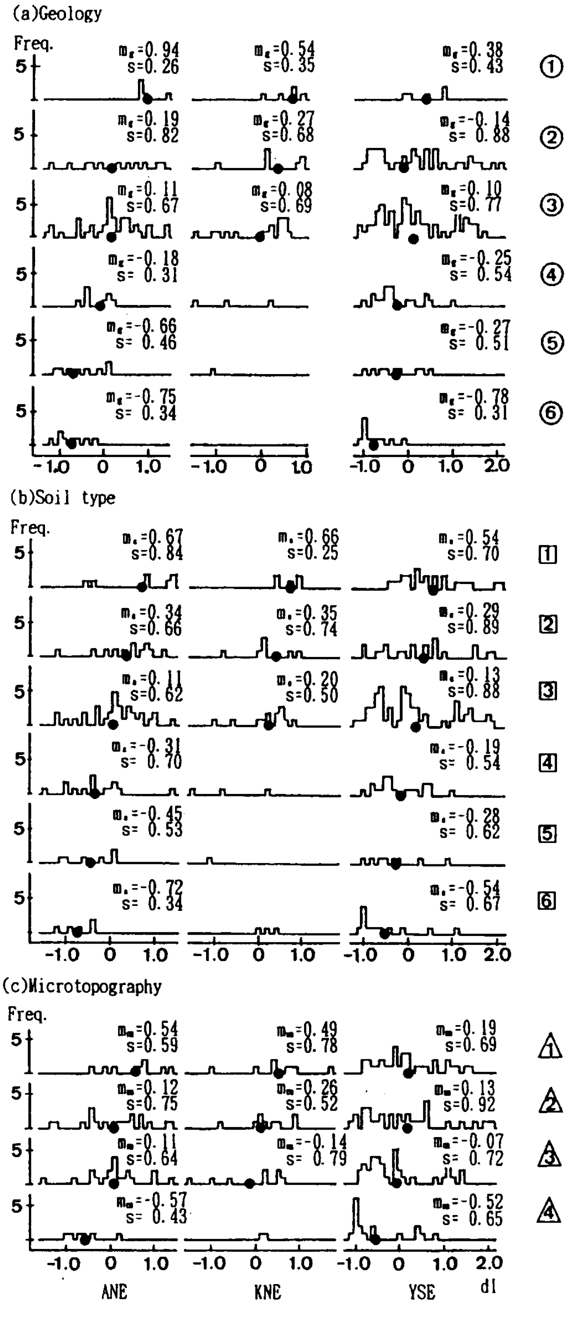

Fig.6 Frequency diagrams of seismic intensity deviations dI for each category of the surface layers.m:averaged value (● marks), s:standard deviation
①: Reclaimed land(after 1588), ②: Reclaimed land (before 1587), ③: Fan, ④: Terrace gravel bed, ⑤: Aso-pyroclastic flow deposit, ⑥: Pre-Aso volcanic rock etc.,
[1]: Clay, [2]: Sand, [3]: Sand gravel, [4]: Loam plus gravel, [5]: Loam plus tuff, [6]: Loam plus andesite
△1: Back swam, △2: Natural levee, △3: Plateau, △4: Mountainous

hypocentral distance. Therefore these I_A are seismic intensities observed on the baserock, and would be considered as the "input" to the bottom of surface soft layers at each site. Since I_Q at the ground surface are related to the "output", the characteristic value of the system can be expressed by seismic intensity deviation dI as follows;

$$dI = I_Q - I_A \quad (2)$$

This seismic intensity deviation dI is an index to represent a transfer function of the surface layer. In this anlysis, the items of geology, soil types and microtopography of surface layers are taken into consideration. These are classified into more detailed categories as shown in Table 3.

4.1 Geological Characteristics of Surface Layers

According to the analysis procedure denoted in Chapter 3, ground characteristics of surface layers are classified into three modes as shown in Fig. 5. These are soft ground (○ marks; alluvial plain with a thick sedimentary layer composed mainly of clay, etc.), slightly soft ground (× marks; alluvial plain and fan with a relatively shallow sedimentary layer composed mainly of clay and sand, etc.) and hard ground (● marks; plateau, foot of volcano composed of loam plus sand gravel, andesite, etc.). In common with sample earthquakes, the trend of attenuation of questionnaire seismic intensities I_Q appear as a characteristic patterns in every three classified modes of surface layers as shown in Fig. 5.

To investigate this problem in more detail, the geological characteristics are classified into categories shown in Table 3(a) and Fig. 4(a). Then to analyze seismic intensity deviation dI statistically, frequency diagrams of deviation dI are applied for each category of geology and earthquake, respectively, as shown in Fig. 6(a). The geological characteristics are expressed in the averaged value m_g and its standard deviation s, in which circled numbers correspond to geological classification in Table 3(a).

These averaged values m_g of dI in each geological category are shown in Fig. 7(a). Independent of earthquake magnitude and hypocentral distance, the decrement of m_g corresponds fairly well to the category transition of soft to hard in the sense of stiffness which is equivalent to the transition of geological age.

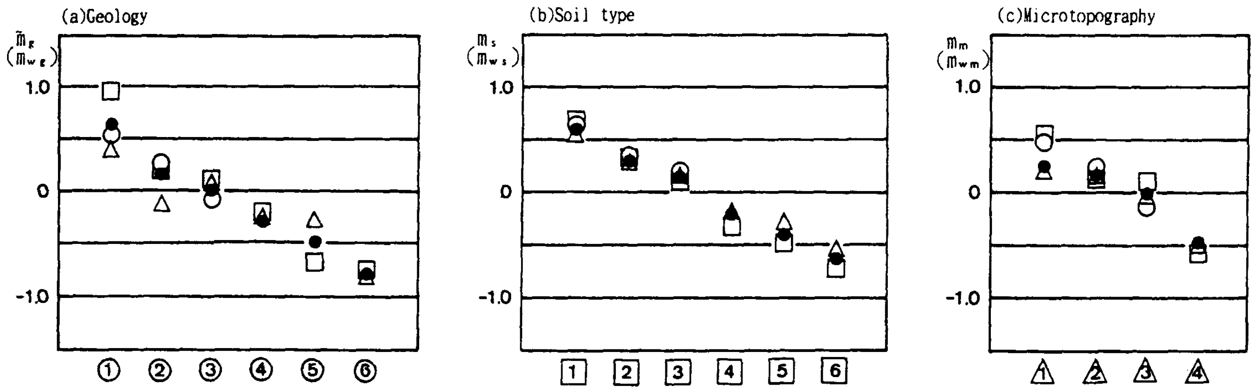

Fig.7 Relation between the averaged values m for each sample earthquake and each category of classified surface ground characteristics.□ : ANE, ○ : KNE, △ : YSE, ● : superimposed data of ANE, KNE and YSE
① : Reclaimed land(after 1588), ② : Reclaimed land(before 1587), ③ : Fan, ④ : Terrace gravel bed,
⑤ : Aso-pyroclastic flow deposit, ⑥ : Pre-Aso volcanic rock etc.,
[1] : Clay, [2] : Sand, [3] : Sand gravel, [4] : Loam plus gravel, [5] : Loam plus tuff, [6] : Loam plus andesite,
△1 : Back swam, △2 : Natural levee, △3 : Plateau, △4 : Mountainous.

4.2 Soil Type Characteristics of Surface Layers

As already described in previous section 4.1, frequency diagrams of the seismic intensity deviation *dI* have shown considerable variation respecting geological characteristics. This requires another key item, such as soil types, thickness and stiffness of soft layer in addtion to the geological one, or another probable factor for the seismic intensity survey, etc. Here, the soil type of the alluvium sediment up to the depth of 40m and the basement for the plateau or the foot of volcano have been classified into categories as shown in Table 3(b) and Fig. 4(b).

The results are shown in Fig. 6(b) and Fig. 7(b) after same statistical analyses as above, in which rectangled numbers correspond to soil type classification in Table 3(b). Independent of earthquake magnitude and hypocentral distance, averaged values m_s of *dI* in each category of soil type basically vary depending in the category of the alluvium sediment and the plateau or foot of the volcano.

In the case of alluvial sediment, according to Fig. 7(b), the decrement of m_s corresponds fairly well to the category variation of small to large in the grading or the solidity, or from clay to sand and gravel in soil type. In the case of plateau or foot of volcano where the soft layer is extremely thin, the declement of m_s corresponds fairly well to increment of grain size in upper surface layer (clay to loam) in addition to stiffness variation (soft to hard) of the lower diluvium layer such as sand, gravel, tuff, andesite, etc.

4.3 Microtopography Characteristics

Similar analyses have been done using classification of microtopographical category as shown in Table 3(c) and Fig. 4(c). Their statistical results for *dI* are shown in Fig. 6(c) and Fig. 7(c), in which triangled numbers correspond to topographical classification in Table 3(c).

Then according to Fig. 6(c) and Fig. 7(c), the averaged values m_m of *dI* for the three sample earthquakes corresponds fairy well to the sense of stiffness of surface layer according to the formation process of microtopography. However microtopography shows the small changes between topographic categories. More detailed surveys are required for microtopographic classifications in the furture.

4.4 Cross-correlated Evaluation of Averaged Values

To check the reliablity of averaged value m (:m_g, m_s and m_m) of *dI* for each category of geology, soil type and microtopography in surface layers, the cross-correlation have been investigated. Fig. 8(a)

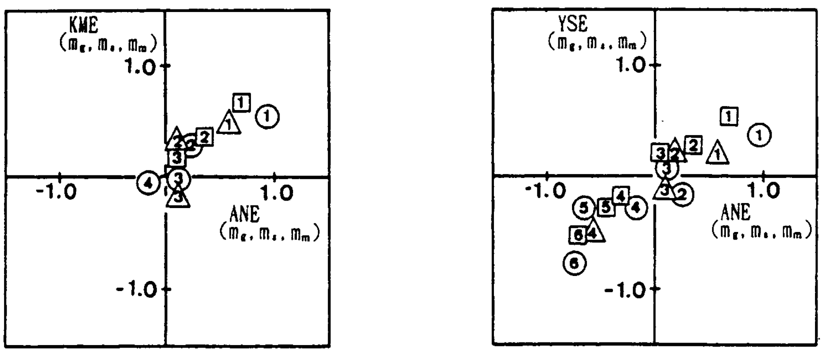

Fig.8 Cross-correlation of averaged values of each category for surface ground characteristics between ANE and KNE or YSE. ① : Reclaimed land(after 1588), ② : Reclaimed land(before 1587), ③ : Fan, ④ : Terrace gravel bed, ⑤ : Aso-pyroclastic flow deposit, ⑥ : Pre-Aso volcanic rock etc.,
[1] : Clay, [2] : Sand, [3] : Sand gravel, [4] : Loam plus gravel, [5] : Loam plus tuff, [6] : Loam plus andesite,
△1 : Back swam, △2 : Natural levee, △3 : Plateau, △4 : Mountainous.

and (b) are the diagrams of cross-correlation between these averaged values m for the sample earthquake ANE versus the earthquake KNE or YSE, in items of geology, soil types and microtopography with different marks. These averaged values m for each category of ground characteristics are distributed around a straight line of an angle of 45°, which means almost perfect correlation between both coefficients. These diagrams show the good correlation between averaged values for different earthquakes as well as for each category of geology, soil type and microtopography of surface layers. Thus its reliability has been verified quantitatively.

Thus intensity deviations dI and these averaged values m can be defined as the reliable quantitative measures for categories of local ground characteristics at the site. Using intensity deviations dI and these averaged values m calculated for the three sample earthquakes, it may extend to the reliable seismic microzonation.

5. Examination of Extent of Shaking for Surface Layers

These averaged values m_g, m_s and m_m have been calculated for the sample earthquakes. There seems to be a small variation in averaged values as shown in Fig. 6, Fig. 7 and Fig. 8.

Using the whole superimposed data of seismic intensity deviations dI for the three sample earthquakes, the same statistical analyses have been applied for each category of geology, soil type and microtopography. These frequency diagrams and their averaged values (m_{wg}, m_{ws} and m_{wm}) for each category are shown in Fig. 9 and also plotted these results in Fig. 7 (shown in ● markes). These averaged values m_{wg}, m_{ws} and m_{wm} correspond fairy well to the trends of geological age or sense of ground stiffness for geotechnical characteristics which was described above for each of the three sample earthquakes. Therefore, the averaged values m_{wg}, m_{ws} and m_{wm} can be defined as the reliable quantitative indices for each category of ground characterisric of surface layers already shown in Table 3. These

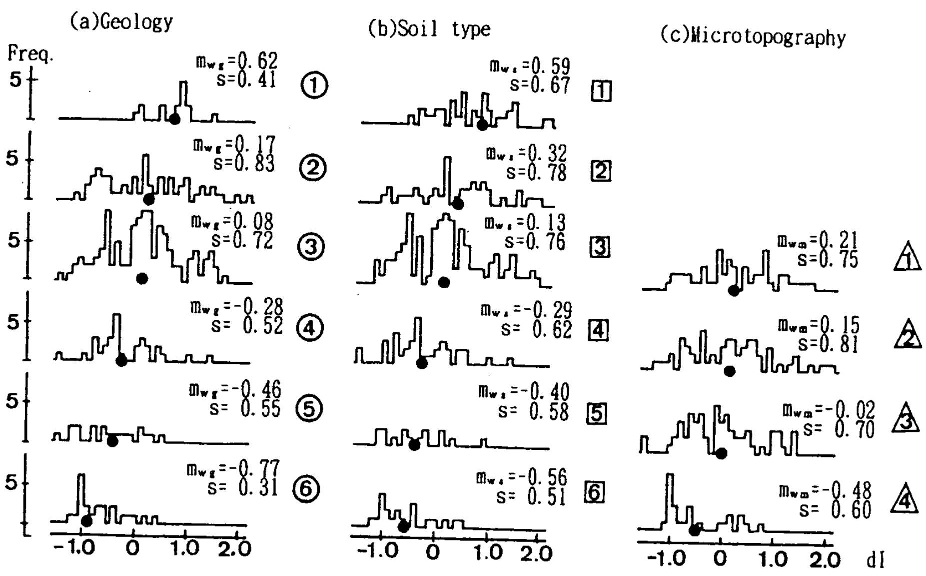

Fig.9 Frequency diagrams of superimposed data of seismic intensity deviations dI for sample earthquakes ANE, KNE and YSE for each category.
m : averaged value (● marks), s : standard deviation
①: Reclaimed land(after 1588), ②: Reclaimed land(before 1587), ③: Fan, ④: Terrace gravel bed, ⑤: Aso-pyroclastic flow deposit, ⑥: Pre-Aso volcanic rock etc.,
[1]: Clay, [2]: Sand, [3]: Sand gravel, [4]: Loam plus gravel, [5]: Loam plustuff, [6]: Loam plus andesite,
△1: Back swam, △2: Natural levee, △3: Plateau, △4: Mountainous.

results are consistent with the results of Okada *et al.* [7] and Nogoshi [8].

Using about 1,500 bore samples in and around Kumamoto City, authors have analyzed the ground structure up to 200~300m in depth and defined the engineering baserock (:hard layer of more than SPT-N value of 50). Cross-correlation between intensty deviation dI and thickness T_{50} of surface soft layers (less than SPT-N value of 50) or its regression line have been demonstrated in Fig. 10. The regression line will be written by

$$dI = 0.02T_{50} - 0.42 \quad \text{(correlation coefficient} = 0.38) \tag{3}$$

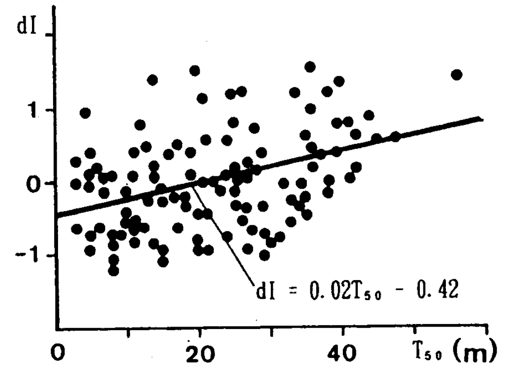

Fig.10 Relationship between seismic intensity dI and thickness T_{50} of surface soft layers(less than SPT-N value 50).

This regression line gives positive linear relation between intensty deviation dI and thickness T_{50}. This shows that thickness T_{50} of the surface soft layer can be defined as one of efficient factors to estimate intensity deviation dI at any site.

6. Applicatoin to Seismic Microzonation Based on the Seismic Intensity Deviation

Seismic intensity deviation dI has been demonstrated as the index to characterize the amplification of surface layers. Then these will be expected to be applied to seismic microzonation. Here, plotting simple averaged values δ of seismic intensity deviations dI in each mesh for sample earthquakes ANE, KNE and YSE, approximate seismic microzoning map in Kumamoto City (hereafter called SMKM) is obtained as shown in Fig. 11. In this microzoning map (; SMKM), variation of δ is classified and allocated to rank A ; $\delta \geqq 0.9$, B ; $0.9 > \delta \geqq 0.3$, C ; $0.3 > \delta \geqq -0.3$, D ; $-0.3 > \delta > -0.9$ and E ; $-0.9 \geqq \delta$ which are constructed by intervals of 0.6 for convenience.

Rank A and B in relatively high-level risk correspond to thick clay-layer zones in the alluvium plain and fans in the coastal areas of Ariake Sea where the geology is unstable. Also, rank D and E in very low-level risk mostly correspond to terrace and volcanic piedmont covered with thin loam.

In order to verify these results, frequency diagrams of rank A to E for geological categories described previously in Table 3(a) are determined as shown in Fig. 11. Rank A, B and C are allocated at newly reclaimed land in alluvial plains(: coastal areas). Rank C, D and E seem to be allocated in dilluvial plateau or mountains where the geology is stable.

This seismic microzoning map (; SMKM) in Kumamoto City is considered to reflect fairly well the geological characteristics of the actual ground. This fact will support the validity of seismic microzonation by the seismic intensity deviation method proposed in this study. But in this microzoning map (: SMKM), there are a few mashes in which averaged value δ was calculated from one questionnaire sheet, it is very important to repeat actual questionnaire surveys for future earthquakes.

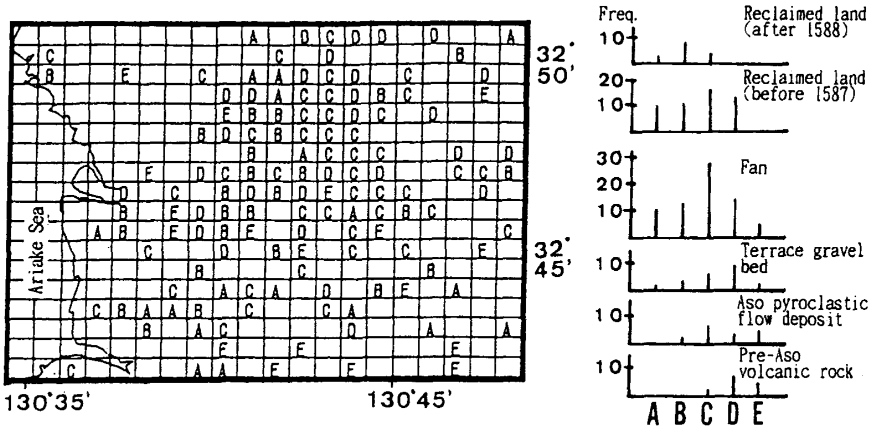

Fig.11 Seismic -deviation- microzoning map in and around Kumamoto City(: SMKM), and its frequency diagrams of rank *A* to *E* for each geological category. A : $\delta \geqq 0.9$, B : $0.9 > \delta \geqq 0.3$, C : $0.3 > \delta \geqq -0.3$, D : $-0.3 > \delta > -0.9$, E : $-0.9 \geqq \delta$

7. Discussion

In 1889, about 100 years ago, Kumamoto City experienced an earthquake of M=6.3, which occured south-east the city and suffered fairly large damage. After that, a remarkable earthquake of M>6 has not occured yet and the number of earthquakes with more than IV on JMA intensity scale are very few around Kumamoto City.

In this paper, the sample earthquakes were of moderate scale, and seismic intensity I_Q has been calculated from a few questionnaires and some residential areas. Since a questionnaire survey must be carried out in residential areas, which are far less than non-residential areas in Kumamoto area, the accuracy of seismic intensity distribution maps are not really satisfactory.

Taking into consideration seismic activity and expansion of residential areas in the future, it is necessary and important to repeat the questionnaire surveys for future earthquakes of moderate-class in and around this region. Then seismic intensity deviation dI at the site will be able to be estimated more correctly, and will develope the empirical formula for estimating seismic intensity at each site based on the ground characteristics which are represented by qualitative data or thickness T_{50} data, etc. of surface soft layers. If such empirical formula be in practical use in the future, the survey area will be extended to non-residential areas and practical application of the seismic microzonation of Kumamoto City will be expected.

8. Conclusions

In this study, using questionnaire surveys for the three moderate earthquakes which recently occurred near Kumamoto City, a new method to estimate ground cahracteristics at the site has been presented and extended to seismic microzonation. The analyses of seismic intensity and quantitative evaluation of ground characteristics of surface layers have been made mostly by statistical procedures. The results are summed up as follows;

(1) Local ground characteristics can be extracted in the form of seismic intensity deviation dI between questionnaire seismic intensity I_Q and Ohta's formula intensity I_A. The estimation of precise seismic intensity distribution maps by questionnaire surveys for moderate earthquakes is possible.

(2) Intensity deviation dI in each mesh and its averaged values m_{wg}, m_{ws} and m_{wm} can be defined as the quantitative indices of seismic response at local sites for each category of geology, soil types and microtopography. Furthermore, this seismic intensity deviation dI can be explained by thickness T_{50}

of surface soft layers (less than SPT-N value of 50).

(3) The proposed method shows that highly accurate ground characteristics of surface soft layers can be obtained by increasing and overlapping seismic intensity distribution maps due to questionnaire surveys, and the use of accurate ground chatacteristics leads to precise application for seismic microzonation.

In addition, the effect of many other ground conditions such as the quantitative stiffness or amplification factor, etc. will be investigated independently and mutually. These comprehensive results will be reported soon after the examination and analyses.

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アンケート震度調査による表層地盤特性の抽出と
地震地盤危険度評価への適用性

宮崎 雅雅*・秋吉 卓**・尻無濱昭三***

要 旨

太田他が開発したアンケート震度調査による高密度な震度分布図に基づき，都市の地震地盤特性を評価する簡便な方法を提案し，サイスミック マイクロゾーニングへの適用性を検討した。調査した地震は，熊本市とその周辺地域に発生した震源位置やマグニチュードの異なる，3個のやや顕著地震である。本研究では，地震震度による地震地盤特性を評価する指標として，アンケートによる震度I_Qと震源距離による震度の一般的な減衰式より得られるアテネーション震度I_Aとの震度差dIを導入し，この震度差dIが，地震特性に無関係な，局所的な地震地盤特性の差異を反映することを明らかにした。また，本指標をもとにした解析手法を適用し，熊本市とその周辺地域のサイスミック マイクロゾーニングマップを作成し，その適用拡大の可能性を確認した。

キーワード：地震震度，震度の減衰性，アンケート震度調査，サイスミック マイクロゾーニング，表層地盤の地震特性，やや顕著地震

* 九州東海大学工学部建築学科
** 熊本大学工学部土木環境工学科
*** 鉄建建設技術研究所