PROPOSAL OF THE CONDITIONAL PROBABILISTIC HAZARD MAP

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ABSTRACT :

We propose the probabilistic seismic hazard map for the study of earthquake risk of spatially-spreaded facilities. This is introduced as the conditional seismic hazard map which is the expectation of the ground motion intensity at the secondary site on the condition that the given ground motion intensity at the primary site occurs. As application, the maps of two areas of Japan are estimated and study the effectiveness.

KEYWORDS: PSHA, Seismic Hazard Map, Spatial Correlation

1. INTRODUCTION

Probabilistic seismic hazard technique developed by Cornell(1968) have been sophisticated in step with the advances in elemental technology such as empirical attenuation equations. Recently, the probabilistic hazard maps estimated by this technique have been widely used for the setting of earthquake loads for structures or the calculation of earthquake insurance rate, and so on. However, in drawing up these hazard maps, the each points on the maps are calculated independently, since the dominant earthquake for each points may be different. Therefore, it's not adequate for the study of facilities distributed in wide area. Just as examples, the estimation of seismic risk of the infrastructure as typified by electricity, gas and water needs to consider the events that multiple facilities are damaged simultaneously. Heretofore, we used the hazard map of scenario earthquake for such purposes. But, the damage by unidentified faults of recent years emphasized the need for probabilistic hazard analysis for wide areas. This paper proposes the conditional seismic hazard map which is the expectation of the ground motion intensity at the secondary site on the condition that the given ground motion intensity at the primary site occurs. This hazard map enables us to consider probabilistically the correlation of ground motion for multiple sites. As application, the two areas in Kanto and Kansai districts of Japan are employed, followed by the conditional seismic hazard maps corresponding to some ground motion intensities at the primary site, and examine the application of this map.

2. ESTIMATION THE CONDITIONAL PROBABILISTIC HAZARD MAP

In estimating the conditional probabilistic hazard map, at first, we must select the primary site where have most important facilities of the estimated area. Another point other than primary site are called secondary site in this estimation. Seismic hazard at primary site are evaluated by normal PSHA procedure. One at secondary site are evaluated the conditional seismic hazard of primary site' seismic hazard.

2.1. SEISMIC HAZARD AT PRIMARY SITE

Seismic hazard is expressed as annual exceedance probability $P(a)$, and when Poisson process is assumed as a process of the earthquake occurrence, $P(a)$ is given by:

$$P(a) = 1 - \exp[-\nu(a)] \tag{1}$$

where $\nu(a)$ is annual frequency which the earthquake ground motion intensity exceeds a.

The seismic hazard of a primary site is obtained as a sum total of the earthquake hazard due to enormous earthquake events generated by seismic source zone model. This is given by:

$$\nu(a) = \sum_{i=1}^{N} \nu_i p_i(a) = \sum_{i=1}^{N} \nu_i \Phi\left[\frac{\ln(\overline{A}_i / a)}{\beta}\right] \tag{2}$$

Where,

ν_i : Annual frequency of event i

$p_i(a)$: Annual exceedance probability which the earthquake ground motion intensity exceeds a

$\overline{A}_i$: Median of ground motion intensity due to earthquake event i

β : Logarithmic standard deviation of estimated residuals of empirical attenuation equation

$\Phi[\cdot]$: Standard normal distribution

N : Total number of events

2.2. SEISMIC HAZARD AT SECONDARY SITE

The seismic hazard of secondary site is defined as expect value of earthquake motion caused by the same incidence when ground motion intensity hit the primary site. Event frequency $\lambda_i(a)$ which given ground motion intensity a due to event i occurs at secondary site is given by:

$$\lambda_i(a) = \nu_i \times \left(\Phi\left[\frac{\ln\{\overline{A}_i /(a-\Delta a)\}}{\beta}\right] - \Phi\left[\frac{\ln\{\overline{A}_i /(a+\Delta a)\}}{\beta}\right]\right) \tag{3}$$

where, Δa is disaggregation range of ground motion intensity and is appropriately set.
Earthquake ground motion intensity a and Medium value $\overline{A}_i$ of earthquake ground motion intensity is related as below:

$$a = \overline{A}_i \times \exp(\alpha\beta) \tag{4}$$

where, α is the coefficient of the variation from the median value.
The variation of the empirical attenuation equation is disaggregated to two types of variations. One is the variation of source, which is due to the destruction process of fault. Other is the variation of earthquake motion propagation, which is due to the path or site amplification. When the logarithm standard deviation β_1, β_2 of the empirical attenuation equation by the former and the latter are assumed independently, β_1, β_2 are related as below:

$$\beta^2 = \beta_1^2 + \beta_2^2 \tag{5}$$

Eq.(4) are as follow by using β_1, β_2:

$$a = \overline{A}_i \times \exp(\alpha_1\beta_1 + \alpha_2\beta_2) \tag{6}$$

where, α_1, α_2 are the coefficients which also show the variation from the median value. α_1, α_2 are given as follow:

$$\alpha_i = \alpha \times \beta_i / \beta, \quad i = 1,2 \tag{7}$$

The variation of source is thought to be common about a primary site and secondary site. Meanwhile, the variation of propagation is thought to have the correlation in according to the intersite distance between the primary site and the secondary site. Therefore, ground motion intensity $\tilde{a}_{j|i}(a)$ when ground motion intensity a at primary site by event i is defined below:

$$\tilde{a}_{j|i}(a) = \overline{A}_{j|i} \times \exp(\gamma_1 \alpha_1 \beta_1 + \gamma_2 \alpha_2 \beta_2) \tag{8}$$

where, $\overline{A}_{j|i}$ is medium value of the ground motion intensity at secondary site j due to earthquake event i. γ_1, γ_2 are the correlation coefficients of estimated residuals by empirical equation between primary site and secondary site. $\gamma_i = 1$ means perfect correlation and $\gamma_i = 0$ means full independence. When $\gamma_i = 0$, it is given the medium value whereas $\exp(\gamma_i \alpha_i \beta_i)$ equals to 1. In this study, we defined γ_i as follows based on the proposal by Hayashi et al.

$$\gamma_i = \exp(-k_i x^{\delta_i}), \quad i = 1,2 \tag{9}$$

where, x is intersite distance between primary site and secondary site, k_i, δ_i are the coefficients which express the reduction of correlation factor.
Expected value $\tilde{a}_j(a)$ of ground motion due to all earthquake events are given by follow:

$$\tilde{a}_j(a) = \sum_{i=1}^{N} \lambda_i(a) \times \tilde{a}_{j|i}(a) \Big/ \sum_{i=1}^{N} \lambda_i(a) \tag{10}$$

And, annual frequency $\lambda(a)$ of ground motion intensity a are given by follow:

$$\lambda(a) = \sum_{i=1}^{N} \lambda_i(a) \tag{11}$$

Seismic hazard curve at secondary site are evaluated from given ground motion intensity and it's annual exceedance frequency by using Eq.(10) and Eq.(11). Above mentioned procedure is illustrated in Figure.1

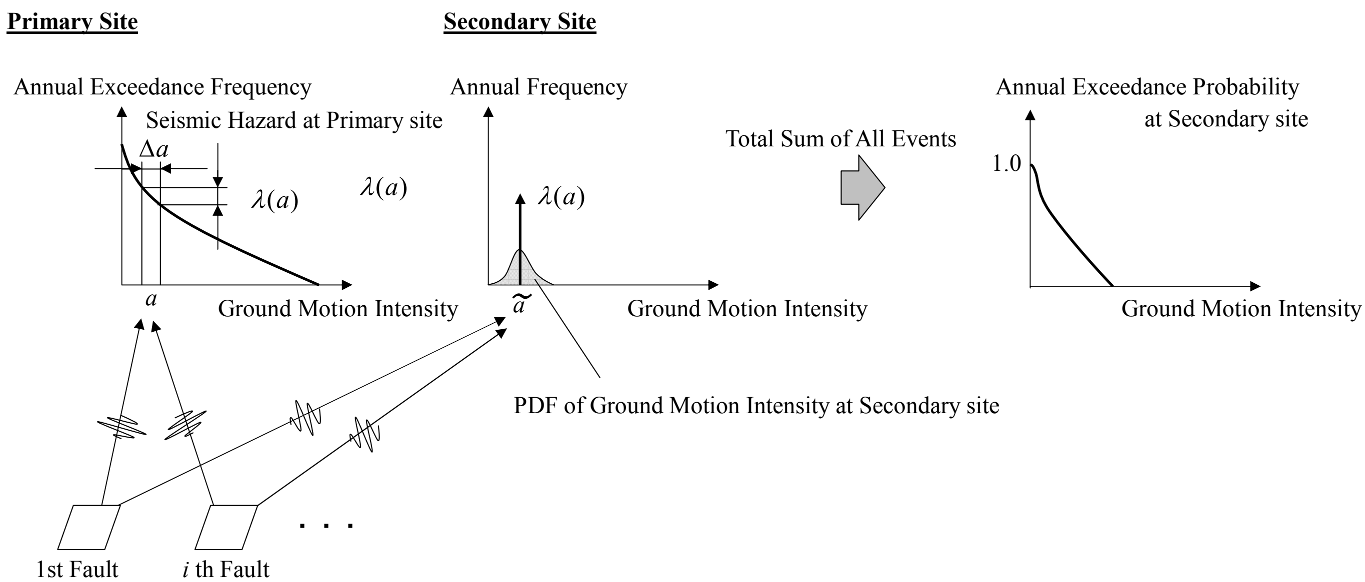


Figure1 Outline of conditional hazard evaluation

3. APPLICATION

3.1. Estimated Area

The conditional probabilistic hazard map is evaluated for the Kanto region and the Kansai region that is the base of industry in east and west of Japan as examples. Primary sites are Tokyo Metropolitan City Hall and Osaka Prefectural Head Office respectively. And secondary site are allocated thoroughly within the range of 200km in the radius to have centered on a primary site. Figure 2 shows the arrangement of a primary site and secondary site. In this figure, marked out circle means primary site, normal circle means secondary site.

3.2. Seismic Source Zone

Seismic source zone model of PSHA in this study is based on Annaka and Yashiro. For seismic source zones corresponding to the active faults and area source where large earthquake occur periodically, the characteristics earthquake model is employed. On the contrary, Gutenberg-Richter model is used for seismic zones where medium or small earthquake occur.

For estimation of ground motion intensity, empirical attenuation equation for peak ground velocity(PGV) by Annaka et al. is employed. For standard deviation of estimated residual by attenuation equation, we assumed that the variation of source is 0.46 (in natural log) and the variation of earthquake motion propagation is 0.47, referring to Hayashi et al. And, for the spatial correlation, we assumed that the correlation about source is full independence and the variation about earthquake motion propagation has the correlation as a function of intersite distance proposed by Hayashi et al. This correlation is shown in Figure 3.

3.3. Soil Amplification and Instrumental Seismic Intensity

For estimation of amplification characteristic in surface soil, amplification factor for PGV is employed referring to Japanese seismic hazard map by the Headquarters for Earthquake Research Promotion that is the Japanese government agency. And, In this hazard map, ground motion intensity are expressed by the instrumental seismic intensity (SI) defined by the Japan Meteorological Agency. Hence, PGV are converted into SI by the equation proposed by Midorikawa et. al. as follow:

$$I = 2.68 + 1.72 \log PGV \tag{12}$$

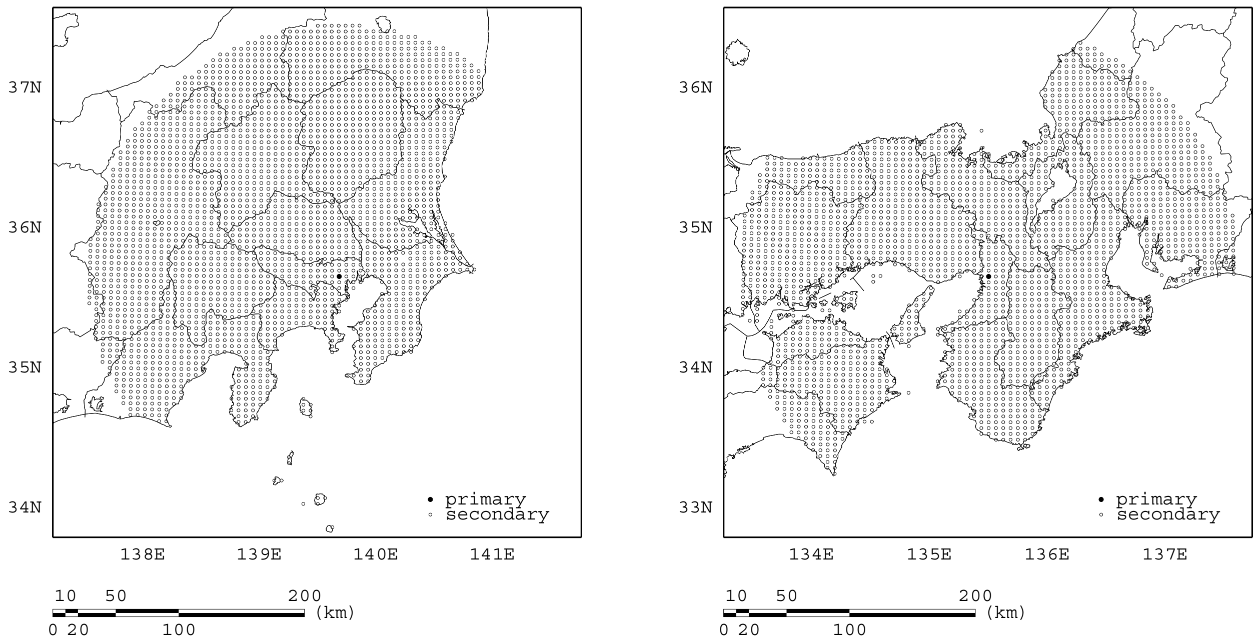
where, I is the instrumental seismic intensity, PGV is peak ground velocity at surface.

3.4. Conditional Seismic Hazard Map

Conditional seismic hazard map is created by the proposal procedure to evaluate SI value corresponding to given annual exceedance probability from the conditional seismic hazard at secondary sites in the estimated region. Figure 4 and Figure 5 show conditional seismic hazard map of Kanto and Kansai region. The value of the annual exceedance probability corresponding to SI:5 strong(5+), 6 weak(6-), 6 strong(6+) at primary site are the condition in these maps. Hence SI at primary site is consistent with the condition in these maps. These figures show conditional SI at secondary sites basically become progressively smaller with distance from the primary site in consideration of spatial correlation of earthquake motion.

The SI distribution of secondary site is different depending on the SI of a primary site. For instance, When SI=5+ at primary site, the dominant earthquake of these map is inland crustal earthquake. So, seismic intensity of secondary site gets exponentially smaller with distance from the primary site. But, When SI=6-, 6+, the coastal big earthquakes greatly influence the seismic hazard of estimated area and the distribution of seismic intensity is smaller with distance from the seismic sources.

In the comparison between Kanto and Kansa region, when SI=6+ at primary site, the map of Kanto region shows that the secondary sites of SI>=6+ are distributed near the primary site, because the fault of Great Kanto Earthquake which is the biggest earthquake in this area is close to the primary site. Meanwhile, in the case of Kansai, the secondary sites of SI>=6+ are distributed in narrow area and the area of SI=6- is widely spread. This means that the primary site is far from the biggest earthquake faults and areal hazard is influenced by various earthquakes.



Kanto region (including TOKYO)

Kansai region (including OSAKA)

Figure 2 Estimated areas

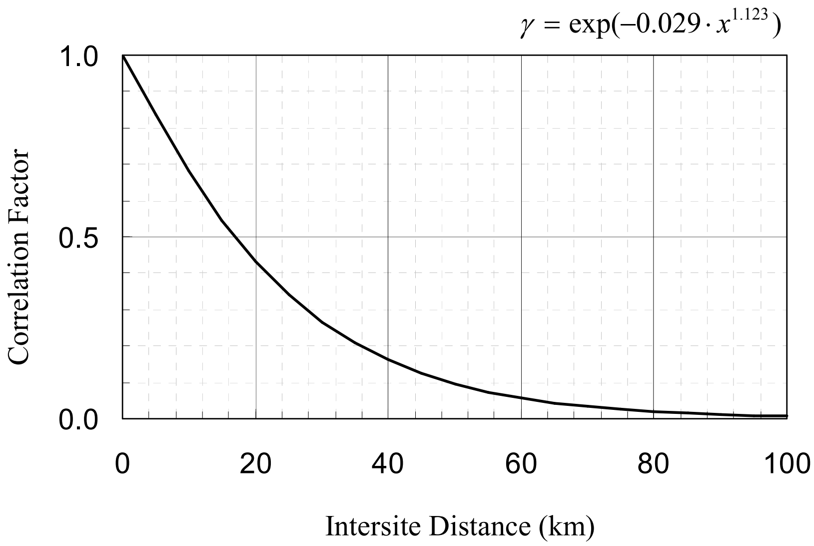
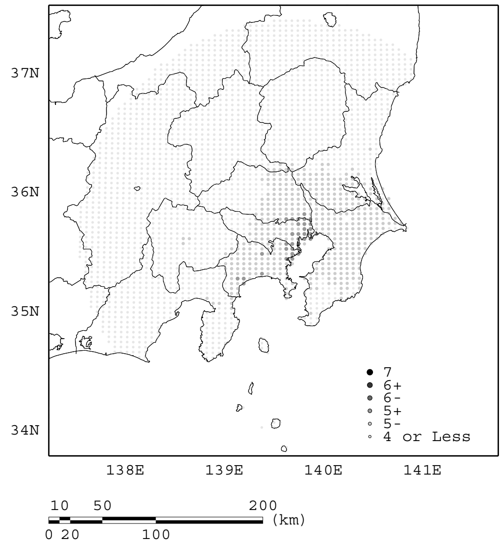
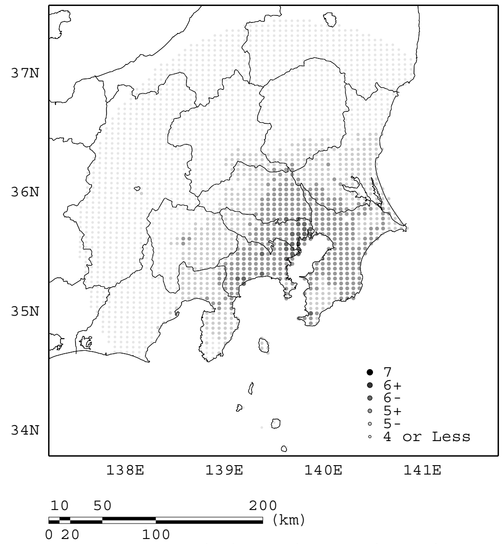


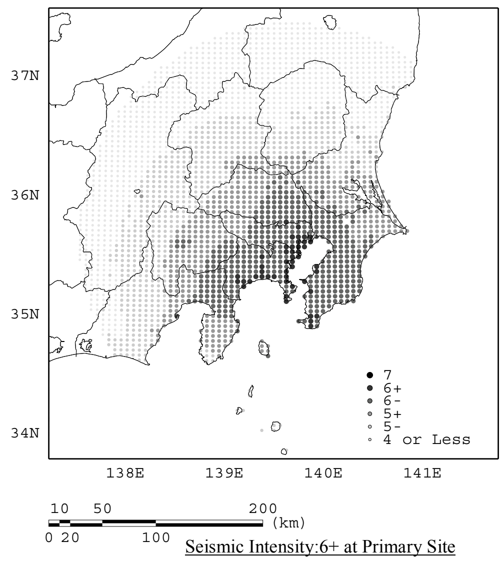
Figure 3 Correlation factor and intersite distance



Seismic Intensity:5+ at Primary Site

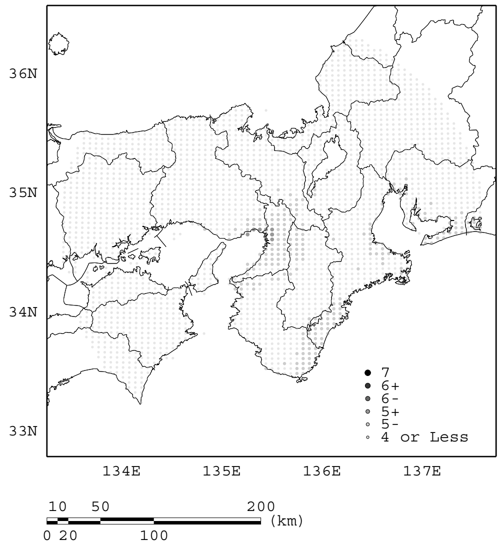


Seismic Intensity:6- at Primary Site

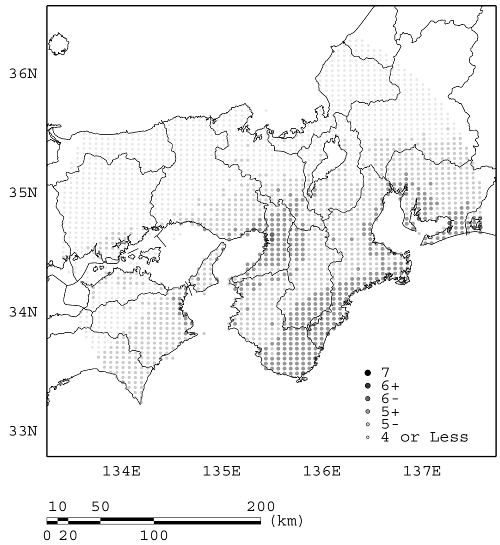


Seismic Intensity:6+ at Primary Site

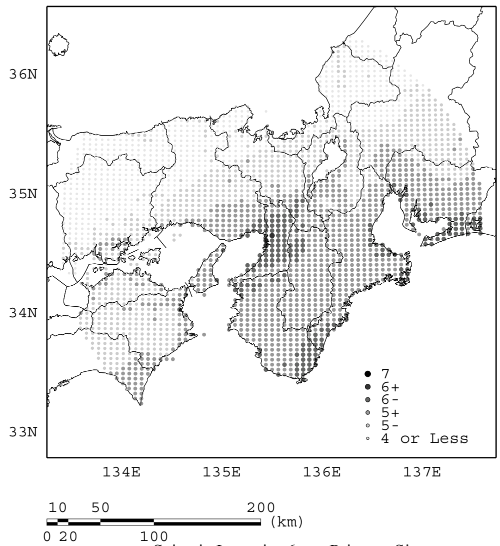
Figure 4 Conditional hazard map of Kanto region



Seismic Intensity:5+ at Primary Site



Seismic Intensity:6- at Primary Site



Seismic Intensity:6+ at Primary Site

Figure 5 Conditional hazard map of Kansai region

4. CONCLUSIONS

We propose the probabilistic seismic hazard map for the study of earthquake risk of spatially-spreaded facilities. This is introduced as the conditional seismic hazard map which is the expectation of the ground motion intensity at the secondary site on the condition that the given ground motion intensity at the primary site occurs. As application, the maps of two areas of Japan are estimated and study the effectiveness.
Ground motion intensity measures at secondary site are strongly influenced by the setting of spatial correlation and the discretization range of probability density function. For the improvement of the evaluation accuracy, the replenishment of the record of observation records and the evaluation of regional are needed.

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