Abstract of Dissertation

NEW PERSPECTIVES FOR PROBABILISTIC PREDICTION OF SEISMIC GROUND MOTION

(地震動の確率的予測法に関する研究)

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The study on the ground motion is one of important parts in the earthquake engineering since the ground motion is the essential link between the earthquake source and the structural response. A seismic risk analysis, for example, can be partitioned into three elements: hazard analysis, vulnerability analysis and loss analysis, where the prediction of the ground motion is a key issue. These factors motive this study to improve the prediction of the ground motion with new perspectives. On the other hand, the accumulation of observations due to the deployment of the seismographic networks in the recent years makes this study possible.

The risk analysis is simplified into three basic cases. They are the cases of a single structure at a single site, multiple structures at a single site, and multiple structures at multiple sites. Although the empirical ground motion attenuation relations have been widely adopted to provide a median value and an uncertainty of prediction to the probabilistic seismic hazard analysis (PSHA), the required information of the probability distribution of the ground motion are different case by case, which cannot be provided only by the existing attenuation relation. This study aims to improve the prediction of the ground motion for each basic case of the risk analysis. The complex risk analysis can then be implemented straightforward through different combinations of three basic cases.

New perspectives were explored based on the empirical data observed from the recent earthquakes for the probabilistic prediction of the seismic ground motion, which is briefly described in the following.

In Chapter 1, the general background of this study was introduced and the objectives of this study were clearly stated. The past studies on the prediction of the ground motion associated with this study were intensively reviewed. Chapters 2 through 4 gave the preliminary required in the following chapters in this study.

In Chapter 2, some basic concepts that would be used in the analyses were defined and classified into four groups. One is the concepts of the risk and elements of the risk. One is the concepts associated with the earthquake, fault, ground motion, and so on. One involves the mathematical concepts such as the deterministic and probabilistic models, likelihood functions, and residual. The last group involves the uncertainty: aleatory and epistemic uncertainties. The former is associated with the randomness while the latter is associated with lack of the knowledge. The latter uncertainty is classified into model and statistical uncertainty.

Chapter 3 introduced the Bayesian methodology. The posterior and predictive analyses were described for noninformative and informative cases, respectively. The advantage of allowing for the prior information in the Bayesian methodology makes one incorporate the prior knowledge, such as knowledge from other disciplines and engineering judgment, etc., into the inference of the unknown parameters. Another advantage is that the statistical uncertainty of the parameters can be accounted for from the Bayesian posterior distribution of the parameters. Another distinctive advantage of the Bayesian methodology is the predictive analysis. Rather than a point estimate of the prediction, a predictive distribution is defined as the expectation of the ground motion on the posterior distribution of the unknown parameters. Therefore the total uncertainty associated with the prediction can be accounted for from the predictive distribution. The features of the Bayesian approach and differences from the traditional estimation were described in detail, which aims to make one familiar with this method.

Chapter 4 dealt with the ground motion. The characteristics of the ground motion are affected by the source, path and site effects, each of which shows large complexity to be fully characterized. After brief review of the two prediction methods of the ground motion: theoretical and empirical methods, the past development of the empirical method were described in detail for one to understand the limitations of the existing approach. These drawbacks include: the median value given by the existing attenuation relation cannot represent those of the specific site, the uncertainty represented in terms of a standard deviation is constant for any sites, and the predicted values are independent of each other. These drawbacks lie in the factors that the data observed from the multiple events and multiple sites are processed together in the development of the attenuation relations with assumption that the observations are independently identically distributed. At the end of this chapter, the uncertainty of the prediction of the ground motion was clarified according to the classification of the uncertainty in Chapter 2. The uncertainty expressed in terms of the standard deviation of the existing attenuation relation was discussed.

Chapters 5 through 7 proposed the new perspectives for the probabilistic prediction of the ground motion, which compensate the shortcomings of the existing attenuation relation mentioned above.

Chapter 5 involved the first case of risk analysis, that is, a single structure at a single site, in which the site-specific attenuation relation was developed for the prediction of the ground motion in lieu of the existing attenuation relation. The conventional site-specific hazard analysis is made with the existing attenuation relation on the reference baseline (a soil category, e.g., rock) and the site amplification factor of the specific site to the reference site. The predictions from this transformation procedure are inaccurate. First, the prediction could have a bias which is the difference between the medians of the observed and the calculated motions for the specific site, because the existing attenuation relation is fitted with observations from different sites and different events, and the site amplification factor cannot fully account for local site conditions. Second, the predictions could have an incorrect dispersion relative to observation. Because the existing attenuation relation is developed with different sites, the uncertainty of the relation only represents the average characteristic of uncertainty of multiple sites. Furthermore, the uncertainty of the site amplification factor is ignored although there is a broad range of soil category. For example, Site category B, rock, in NEHRP provisions is defined as *AVS30* between 760 and 1500 m/s, where *AVS30* is average shear wave velocity in the upper 30 m.

In this study, the ground motion at a specific site was predicted with the site-specific attenuation relation. Rather than developing new attenuation relations, we introduced a correction term to the existing past attenuation equation in common use. The correction term was constructed as the function of the magnitude and distance, and the unknown parameters in the correction term was estimated with Bayesian approach based on the observations at the specific site. The advantages of this analysis procedure are: (1) The use of Bayesian updating technique can incorporate our prior knowledge on the ground motion (e.g., seismological knowledge, engineering judgment) and the observations; (2) Bayesian method can account for the uncertainty of the unknown parameters, which contributes the statistical uncertainty to the total uncertainty of the prediction due to limited number of data observed at the specific site; (3) The predictive density of the ground motion, which is averaged over the posterior distribution of the parameters, is obtained with Bayesian method rather than point estimate of the ground motion, therefore, the prediction accounts for the total uncertainty; (4) The structure of the correction term makes it possible to examine the uncertainty of prediction for different magnitude and different distance, especially, for the area with larger magnitudes and closer distance which is of major interest in the engineering, whereas few observations are available.

In this study, the site-specific attenuation relations for PGA, PGV and Sa were developed, respectively, for the 1558 sites of K-NET and KiK-NET. Both the noninformative and informative priors were adopted in the framework of Bayesian updating. The effects of the noninformative and informative prior on the estimation of the parameters for large-and-moderate size and small size of samples were discussed, respectively. It shows the estimation tends to similar for the different priors when large-and-moderate sizes of observations are available. The estimate of the uncertainty shows they are different from site to site, which implies the assumption of the identical distribution adopted in the existing attenuation relation cannot be satisfied. Three applications were illustrated, including the prediction of the ground motion, the development site-specific attenuation relation for the Hongo campus of the University of Tokyo, the site-specific risk analysis for three buildings in the Hongo campus.

Chapter 6 was devoted to the second case of risk analysis, that is, multiple structures at a single site, in which the joint distribution of the ground motion intensity measures (Sa) for multiple structures is necessary. Under the mild assumption that the joint and conditional distribution of the ground motion is assumed as lognormal, the correlation coefficient between two spectral values at different periods is necessary in addition to the median and uncertainty given by the existing attenuation relation. It is easily understood that the response of the different structures at the same site are somewhat correlated, since they are produced by the same input ground motion, although the response of the structure is only represented by a 5% damping linear response spectral measure of SDOF system in this study.

The correlation model of the spectral accelerations at different periods was developed in this study based on empirical data observed from 31 earthquakes. The model was expressed as a linear function of the log of the ratio of two periods. The results showed the correlation coefficients predicted with the proposed model can meet well with those calculated from the empirical data. The simple form of the model makes the use in practice with great ease. The joint distribution of the ground motion can fully be characterized by the median vector and covariance matrix by using the correlation model proposed in this study as well as the existing attenuation relation. The risk analysis can then follow the conventional procedures. The effects of the different attenuation relations and different soil conditions were examined. It shows the correlation is insensitive to these effects. Three applications also illustrated, including the simulation of the ground motion, joint hazard analysis and estimation of the joint probability of failures.

Chapter 7 involved the third case of risk analysis, that is, multiple structures at multiple sites with one at each site, in which the joint distribution of the ground motion intensity measures, for multiple structures was necessary. Under the mild assumption mentioned above, in addition to the median and uncertainty given by the existing attenuation relation, only the spatial correlation coefficient of the ground motion between two separated sites is needed to fully define the joint distribution and proceed with PSHA. In this study, the macrospatial correlation model was developed for PGA, PGV and Sa, respectively. The model is expressed in a simple form of an exponentially decaying function of the separation distance between two different sites. The only one parameter in the model, called a correlation length, was estimated for 26 earthquakes. In spite of the different attenuation relations and different components of the ground motion, the correlation lengths are the same and most of them fall in the range of 10 to 30 km. Applications to the simulation of the ground motion, evaluation of the joint probability of exceedance and portfolio analysis are illustrated at the end of this chapter.

In Chapter 8, conclusions were drawn and the potential applications and future studies were addressed. The site-specific attenuation relation, the correlation model of spectral values at two periods, and the macrospatial correlation model were developed based on the empirical data, respectively. They are corresponding to the different requirement of the ground motion in three basic risk analyses. Some important reminders should be pointed out. First, three new perspectives are not isolated. They can be and must be combined into different prediction of the ground motion and different risk analysis. Second, the existing attenuation relation was not abandoned but was fully utilized in this study. New perspectives were proposed to compensate the shortcomings of the existing attenuation relation so that the ground motion can be appropriately predicted. Finally, one cannot be limited on the calculated results, but pay more attention to the methodology proposed in this study.