ACCURACY OF SOME GROUND MOTION PREDICTION MODELS FOR PPI STATION-WEST SUMATRA USING OBSERVED STRONG MOTION DATA

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ABSTRACT

This study proposes the ground motion prediction models applicable to PPI Station located in Padang Panjang, West Sumatra, at which 120 components of strong motion data of 40 earthquake events with sampling rate 100 Hz have been recorded, in order to find site-specific parameters used to investigate the site class and the accuracy of the prediction models for this station. The H/V spectral acceleration ratio scheme is adopted to find the dominant period of ground beneath this station since there are no quantitative subsurface soil properties available. The results of H/V analysis show that the mean peak of H/V ratio of EW, NS and total horizontal components to vertical component is around 0.2 second. The peak period of H/V ratio is in good agreement with the geologic information from geological surface map published by Geological Research and Development Center (GRDC, 1973). The geologic formation for the ground beneath and around this station is dominated by quaternary volcanic rock (Qast). Both results indicating the site class for the ground beneath the station could be categorized as rock site with AVS30 more than 600 m/s. The existing prediction models for peak ground acceleration (PGA) and 5% damped spectral acceleration (Sa) at rock site are tested in this study. The accuracy of the selected models is discussed on the basis of the statistical distribution of the logarithmic deviation between the prediction and the observed value. The mean residuals of all prediction models of Sa are found to have the same tendency that they underestimate Sa at period T = 0.2 second and overestimate Sa at T ≥ 0.4 second. It is found that all prediction models show significant period-dependent mean errors and are not allowed to be applied to this site without site correction factors, and among them, Youngs et al., 1997, Kanno et al., 2006, and Zhao et al., 2006 provide the smallest prediction error. Based on these results, it can be concluded that all prediction models may be applied with each site correction factor to reflect the site-specific condition and among them three models proposed by Youngs et al., 1997, Kanno et al., 2006, and Zhao et al., 2006a are the best for this station. However, the error is still large; therefore a further study is needed to check it.

Keywords: peak ground acceleration, 5% damped spectral acceleration, mean residuals.

INTRODUCTION

One of the important factors in the seismic hazard assessment for certain regions is the selection of ground motion prediction model which is also known as attenuation relation model.

There are many attenuation relation model determined by the different definitions of independent variables such as distance, magnitude, site condition, types of faulting and selection of the horizontal ground motion component. Unfortunately, there is no available attenuation model derived

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from using strong motion databases from Indonesia despite Indonesia is located at active tectonic region.

We adopt only some attenuation relation models in both probabilistic and deterministic seismic hazard calculation. However, the selection of suitable attenuation relation for a certain area often causes serious practical problem and doubt since there are more than 206 attenuation relation models to predict PGA and 127 attenuation models to predict response spectra ordinate (Douglas, 2006).

This study will emphasize the scheme in selecting suitable attenuation relation models from some model candidates and also find the site factor for a particular site to account the local site characteristic of the site based on the selected attenuation relation model. Site factor is the mean value of the logarithmic residuals between the observed and predicted values, and evaluated it with the limited observations (Morikawa et al., 2006).

DATA

120 components of qualitative records with sampling rate 100 Hz from 40 events at PPI station used in this study are provided by JISNET-NIED with permission from Meteorological and Geophysical Agency of Republic of Indonesia (BMG Indonesia).

The basic assumptions of earthquake source parameters such as epicenter location, focal depth, magnitude and focal mechanism are referred to CMT and PDE-USGS catalog. Most events, 33 of 40 events are referred to CMT catalog, while the information of other 7 events is referred to PDE-USGS catalog.

39 of 40 events were triggered by subduction earthquake sources. Another one event was triggered by shallow crustal source.

THEORY AND METHODOLOGY

Magnitude Scale

It is an important consideration to use a unified magnitude scale in attenuation study. Therefore in this study, the relation of mb, M_S and M_W is adopted from Scordilis, 2006 in order to unite magnitude scale. By applying these equations, the homogeneity of database will be provided.

Relation between M_W and M_S, for $3.0 \leq M_S \leq 6.1$

$$M_W = 0.67(\pm 0.005)M_S + 2.07(\pm 0.03) \quad (1)$$

Relation between M_W and m_b, for $3.5 \leq m_b \leq 6.2$

$$M_W = 0.85(\pm 0.04)m_b + 1.03(\pm 0.23) \quad (2)$$

Attenuation Relation Models

We select five models for spectral acceleration (Sa) since we cannot cover all existing models in this study. The five models for predicting Sa are Atkinson and Boore, 1997 (AB97); Kanno et al., 2006 (K06-S and K06-D); Midorikawa and Uchiyama, 2006 (MU06-S and MU06-D); Youngs et al., 1997 (Y97-Inter and Y97-Intra); and Zhao et al., 2006a (Z06).

The selected period range for this study is from PGA to T ≤ 2 second based on the most building types, geometries and structures constructed around the particular site (i.e. PPI seismic station) which are dominated by concrete structure buildings with the total number of stories vary from 1 to 8-story buildings.

Site Classification Method

There are some previous studies conducted by several researches related to the determination of site classification with different methods. Two parameters that commonly used in those studies are the average shear wave velocity of top 30 m (AVS30, V_{30} or $\bar{V}_S$) and the dominant period of site (T_G). The relation between them is described in many codes such as NEHRP and Japan Road Association, 1980.

Zhao et al., 2006b used V_{30} (using 0.25 times the site period in four site classes as the shear travel time in the top 30 m soil layers, see Eq. (3)) and site classes used in the Japan Road Association, 1980 and NEHRP Provision (see Table 1).

In this study, H/V response spectral ratio scheme proposed by Zhao et al., 2006 will be adopted to find the dominant period (T_G) of site of PPI seismic station located. The result of H/V scheme will be cross-checked by surface geology around PPI Station based on geology maps of Padang provided by Geological Research and Development Center (GRDC, 1973), Republic of Indonesia.

$$V_{30} = \frac{30}{0.25.T_G} \quad (3)$$

Table 1. Site class definitions used in Japan for engineering design practice and the approximately corresponding NEHRP site classes (Zhao et al, 2006b)

Site class		Site natural period (sec)	Average V_{30} (m/s)	NEHRP class
SC I	Rock/stiff soil	$T_G < 0.2$	$V_{30} > 600$	A+B
SC II	Hard soil	$0.2 \le T_G < 0.4$	$300 < V_{30} \le 600$	C
SC III	Medium soil	$0.4 \le T_G < 0.6$	$200 < V_{30} \le 300$	D
SC IV	Soft soil	$T_G \ge 0.6$	$V_{30} \le 200$	E

RESULTS AND DISCUSSION

Site Class

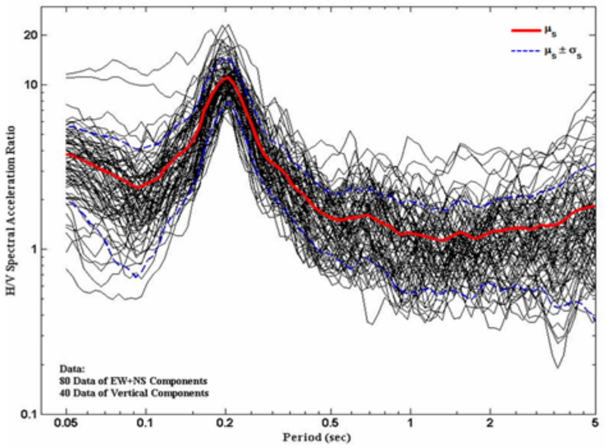

Figure 1. The mean H/V ratio of spectral acceleration at PPI station.

Based on the H/V analysis result, the mean peak ratio of EW and NS components to vertical components is around 0.195 and 0.205, respectively. Figure 1 shows the mean peak ratio of total components to vertical components. By referring to Table 1, the site class beneath PPI Station could be SC I (class A or B) or SCII (class C).

As mentioned earlier, another way as basic engineering judgment to determine site class is that by using the surface geological condition of site beneath and around PPI Station.

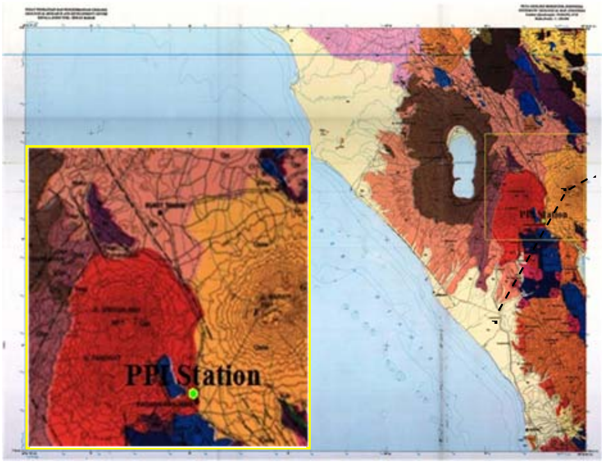

Figure 2. Geology map around PPI station (GRDC, 1973).

Figure 2 shows that the structural geology beneath and around this station is dominated by volcanic rocks (andesit rock, Qast). By referring to NEHRP classification, we may make a preliminary estimate that the site class beneath this station is probably class C (very dense/soft rock) or B (rock). Based on the H/V spectral acceleration ratio and the geological surface condition, the site classification of PPI station can be assumed as rock site (SC I or with the average shear wave velocity of top 30m is predicted more than 600 m/s.

Selecting Candidates

The critical question arisen is how to select appropriate attenuation model for a particular site, i.e. PPI Station. We did statistical analysis for answering that question based on the mean residuals. There are several different ways that can be used to construe the results of the statistical analysis. The first method is to select the best model by using both the lowest mean residual (see Figure 3) and standard deviation (Figure 4) at the required and specific period. The second method is to select two or three satisfactory models and average the predicted ground motions. The last method is to adjust all prediction models by applying a correction factor based on the mean residuals.

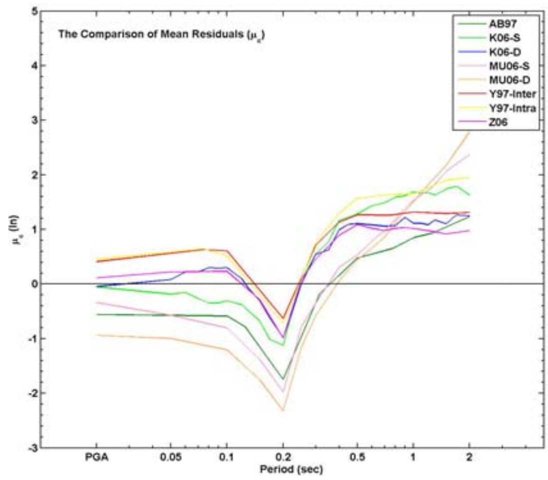

Figure 3. Mean residuals of Sa for all attenuation relation models.

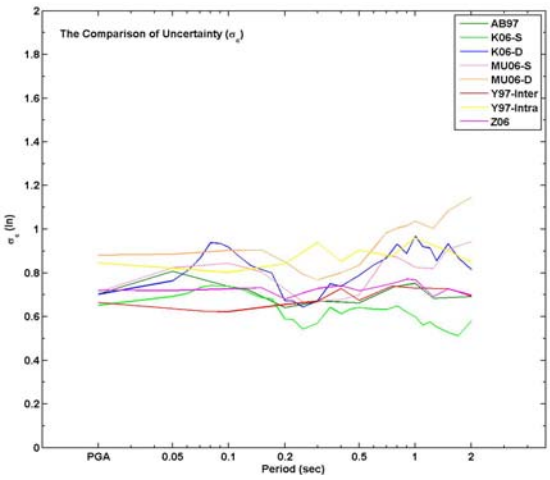

Figure 4. Uncertainty of Sa for all attenuation relation models.

Generally, the decision in selecting the best model will be depended on the application of interest. Related to the first method, some findings can be used as guidance to justify which one is the most appropriate among the used models in this study. The important thing based on the mean residuals (see Figure 3) is that all models have the same tendency which underestimated to predict Sa at period T = 0.2 second and overestimated to predict Sa at $T \geq 0.4$ second. At the short period range, Zhao et al., 2006 and Kanno et al. 2006 attenuation relation models provided smaller mean residuals for PGA and $T < 0.1$ second (relatively), than the other models did; and Youngs et al., 1997 for both interface and intraslab events obtained the smallest mean residuals among others models for period $0.15 \leq T < 0.25$.

Another important finding is that the comparison of uncertainties presented in Figure 4 for various period ranges. It can be concluded that at the short period, for PGA and $T < 0.2$, Youngs et al,. 1997 attenuation relation model for interface events has the smallest uncertainty value while Kanno et al., 2006 attenuation relation model for shallow events has the smallest one for period $T \geq 0.2$ second. We may say that Youngs et al., 1997, Kanno et al., 2006 and Zhao et al., 2006 are suitable for this station. Note that 39 of 40 events used in this analysis were triggered by subduction sources, hence we could not say too much about the prediction of ground motions for crustal event since only one event is available in the data base.

Site Correction Factor Based on Mean Residuals

The site correction factors can be defined as the factors determined by the average residuals treating the adjusted attenuation relation model as a site-specific model. The relation between the original and the adjusted model can be expressed by Eq. (4).

$$\ln y(t)^* = \ln y(t) + s(t) \quad \text{or} \quad \log y(t)^* = \log y(t) + s(t) \tag{4}$$

Where y(t)* is the adjusted model, y(t) is the original model and s(t) is the site correction factor at period t. The site correction factors for all prediction models are represented in Figure 5.

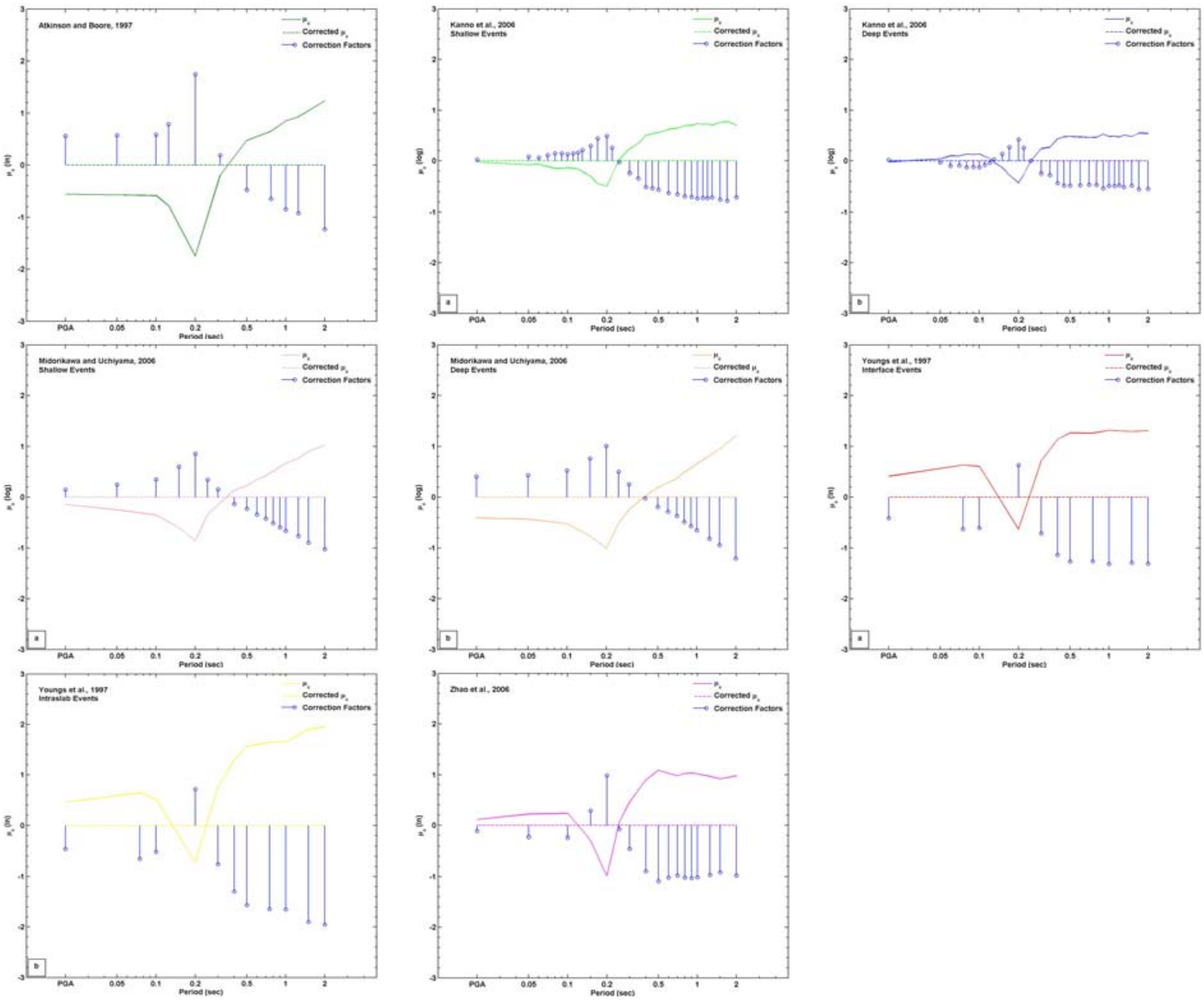

Figure 5. Site correction factors for various attenuation relation models.

CONCLUSIONS

Site correction factors for all models are determined based on the value of mean residuals. Note that these corrections are made only for mean predictions, not for uncertainty predictions. We can adjust the predicted value from each model for PPI station by adding these correction factors into the base models of each attenuation relation model, (see Eq. (4)). Then all prediction models may be applied with each site correction factor to reflect the site-specific condition and among them three models proposed by Youngs et al., 1997, Kanno et al., 2006, and Zhao et al., 2006a are the best for this station. However, the error is still large; therefore a further study is needed to check it.

RECOMMENDATION

As future studies, estimation of site correction factors for other sites, development of possible methods for reducing prediction errors which are still large, and nation-wide deployment procedure to develop site-specific ground motion prediction models.

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REFERENCES

Atkinson, G. M., and Boore, D. M., 1997, Seismological Research Letters, 68, 74–85.

Douglas, J., 2006, BRGM/RP-56187-FR.

Fukushima, Y., and Tanaka, T., 1990, Bulletin of the Seismological Society of America, 80, 757-783.

Geological Research and Development Center (GRDC), 1973, Quadrangle Padang, 0715

Japan Road Association, 1980, Maruzen Co., LTD.

Kanno, T., Narita, A., Morikawa, N., Fujiwara, F., and Fukushima, Y., 2006, Bulletin of the Seismological Society of America, Vol. 96, No. 3, pp. 879–897.

Midorikawa, S., and Ohtake, Y., 2004, 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, Paper No. 325.

Morikawa, N., Kanno, T., Narita, A., Fujiwara, H., and Fukushima, Y., 2006, Japan Association for Earthquake Engineering, vol. 6, No. 1 (in Japanese).

NEHRP, 2000, FEMA 368/369, Washington, D. C.

Scordilis, E. M., 2006, Journal of Seismology, 10, 225-236.

Uchiyama, Y. and Midorikawa, S., 2006, Journal of Struc. and Const. Eng., AIJ, 606, 81-88.

Youngs, R. R., Chiou, S. J., Silva, W. J., and Humphrey, J. R., (1997), Seismological Research Letters, 68, 58-73.

Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., Ogawa, H., Irikura, K., Thio, H. K., Somerville, P. G., Fukushima, Ya., and Fukushima, Yo., 2006a, Bulletin of the Seismological Society of America, Vol. 96, No. 3, pp. 898–913.

Zhao, J. X., Irikura, K., Zhang, J., Fukushima, Y., Somerville, P. G., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., and Ogawa, H., 2006b, Bulletin of the Seismological Society of America, Vol. 96, No. 3, pp. 914–925.