Quantification of Degree of Nonlinear Site Response

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ABSTRACT :

We investigate nonlinear site response based on strong motion records form the 2003 off-Miyagi intraslab earthquake. First we identify the nonlinear site response using records obtained at KiK-net stations where vertical array has been installed. The nonlinear site response is identified by two methods; one is a spectral ratio of surface S-wave to borehole S-wave (surface/borehole) and the other is a spectral ratio of horizontal S-wave to vertical S-wave (S-H/V) for surface records. We confirm that two methods show similar results, so we extended nonlinear identification to records obtained at K-NET stations, where only a surface instrument has been installed, by using the S-H/V method. Next we define a degree of nonlinear site response (DNL) based on the surface/borehole and S-H/V spectral ratio; the DNL is summation of differences between the ratio for strong motion and that for weak motion. We find that the DNL values increase with observed PGA (Peak Ground Acceleration). Finally we make a comparison between the predicted and observed PGAs during the 2003 off-Miyagi Earthquake as a function of DNL. The strong motion prediction is done by using empirical Green's function method. A fairly good agreement is obtained at stations with small DNL. However, the agreement considerably decreases at stations with large DNL; the predicted PGA is much larger than the observed one. We conclude that the reduced observed PGA is due to nonlinear site response during strong ground motion.

KEYWORDS: Nonlinear Site Response, S-wave H/V, Strong Ground Motion Prediction, EGF Method

1. INTRODUCTION

It is very common phenomenon that the seismic response characteristics of surface soft soil become nonlinear when the site is struck by strong motion. From the results of dynamic soil test, it is known that damping factor *h* rises and shear rigidity of soil drops as the shear strain level rises. At the same time, shear wave velocity (*Vs*) related to shear rigidity also drops. The nonlinearity of site response is attributed to these changes of surface soil response due to strong ground motion (Midorikawa, 1993). Especially, the reduction of high frequency seismic waves by increased damping factor often becomes very significant. Because of that, the results of strong motion prediction are sometimes overestimated considerably, especially at PGA. It might be due to nonlinearity of site response contained in strong motion record. The overestimation is expected to be due to the assumption in prediction that the site response is linear regardless the strength of ground motion.

To investigate nonlinear site response, the data recorded at a vertical array are commonly used (e.g., Iai *et al*, 1995). The vertical array data is available at KiK-net stations. But at ground surface observation only stations like K-NET, nonlinear site response cannot be identified using above method. About this issue, Wen *et al*. (2006) suggested that the spectral ratio of horizontal to vertical for S-wave (S-H/V) at ground surface can be used as an indicator of nonlinear site response. We examine the availability of S-H/V using KiK-net vertical array data recorded during the 2003 off-Miyagi Earthquake. To test the behaviors of these ratios, we calculated theoretical response using a model structure using equivalent linear method.

Next, to check the characteristics of nonlinear site response quantitatively, we present the index of nonlinearity of site response DNL. We investigate the relation between DNL for S-H/V and strength of ground motion or soil parameter using data of KiK-net and K-NET. Finally, we compare the DNL with overestimated PGA of strong motion prediction. If the overestimation of PGA is due to nonlinear site response, the DNL would be